



Electric, Mixed-Power, Hydrogen-Powered, Nuclear-Powered and Single-Engine Aircrafts

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Chapter 1

Electric Aircraft



Helios electric-powered UAV

An **electric aircraft** is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultracapacitors, power beaming, and/or batteries.

Currently flying electric aircraft are mostly experimental demonstrators, including manned and unmanned aerial vehicles. Electrically powered model aircraft have been flown since the 1970s, with one report in 1957.

History

In 1883 Gaston Tissandier was the first to use electric motors in airship propulsion. The following year, Charles Renard and Arthur Krebs flew La France with a more powerful motor.

Nikolai Tesla envisaged using electrically powered aircraft, powered by beams from the ground or the ionosphere.

Electric motors have been used for model fixed-wing aircraft since from at least 1957, with a challenged claim from 1909.

In 1964 William C. Brown demonstrates on CBS News with Walter Cronkite a model helicopter that receives all of the power needed for flight from a microwave beam.

In 2007 the non-profit CAFE Foundation held the first Electric Aircraft Symposium in San Francisco.

Experimental projects

1970s and 1980s

Sunrise

The 27 lb (12 kg) unmanned AstroFlight Sunrise, the result of an ARPA contract, made the world's first solar-powered flight from Bicycle Lake, a dry lakebed on the Fort Irwin Military Reservation, on 4 November 1974. The improved Sunrise II flew on 27 September 1975 at Nellis AFB.

Solar Riser

The world's first official flight in a solar powered, man carrying aircraft took place on April 29, 1979. The Mauro Solar Riser was built by Larry Mauro and was based on the UFM Easy Riser biplane hang glider. The aircraft used photovoltaic cells that produced 350 watts at 30 volts, which charged a Hughes 500 helicopter battery, which in turn powered the electric motor. The aircraft was capable of powering the motor for 3 to 5 minutes, following a 1.5 hour charge, enabling it to reach a gliding altitude.

Solar One

The Solar-Powered Aircraft Developments Solar One was designed by David Williams under the direction of Freddie To, an architect and member of the Kremer prize committee and produced by Solar-Powered Aircraft Developments. A motor-glider type aircraft originally built as a pedal powered airplane to attempt the Channel crossing, the airplane proved too heavy to be successfully powered by human power and was then converted to solar power, using an electric motor driven by batteries that were charged

before flight by a solar cell array on the wing. The maiden flight of Solar One took place at Lasham Airfield; Hampshire on June 13, 1979, one day after Brian Allen had successfully pedalled the Gossamer Albatross across the English Channel.

Gossamer Penguin and Solar Challenger

The Gossamer Penguin, a smaller version of the human powered Gossamer Albatross was completely solar powered. A second prototype, the Solar Challenger, flew 262 km (163 mi) from Paris to England. On 7 July 1981, the aircraft, under solar-power, flew 163 miles from Cormeilles-en-Vexin Airport near Paris across the English Channel to RAF Manston near London, flying for 5:23. Designed by Dr. Paul MacCready the Solar Challenger set an altitude record of 14,300 feet.

Solair 1

The human piloted Solair 1 was developed by Günther Rochelt and based on a Farner canard design. It employed 2499 wing-mounted solar cells giving an output of between 1.8 kW (2 hp) and 2.2 kW (3 hp). The aircraft first flew at Unterwössen, Germany on 21 August 1983. It flew for 5 hours and 41 minutes, "mostly on solar energy and also thermals". The aircraft is now displayed at the German Museum in Munich. The newly developed piloted Solair II made its first flight in May 1998 and further test flights that summer but the propulsion system overheated too fast. Development stopped when Günther Rochelt suddenly died in September 1998.

NASA Pathfinder and Helios

NASA's Pathfinder and Helios were a series of solar and fuel cell system-powered unmanned aircraft. AeroVironment, Inc. developed the vehicle under NASA's Environmental Research Aircraft and Sensor Technology program.

1990s



Solar Flight's *Sunseeker* flying over Southern California's high desert

Sunseeker

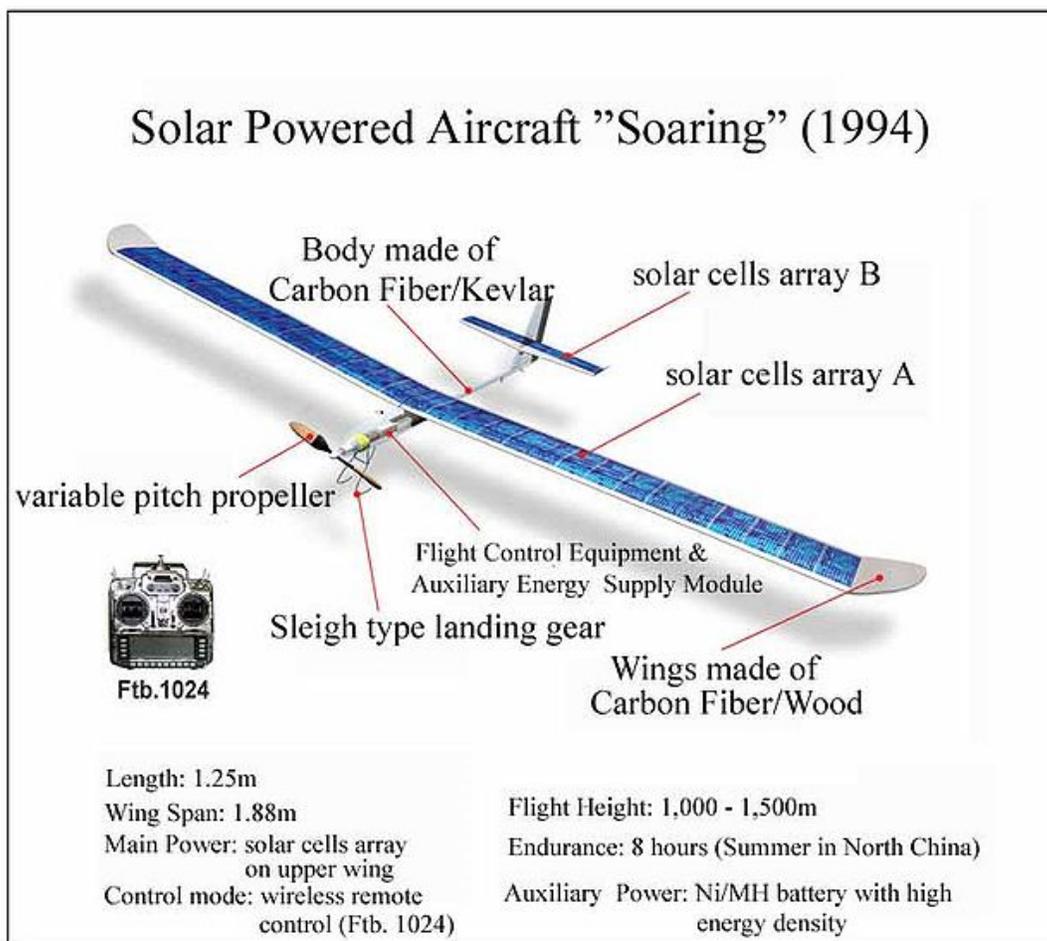
In 1990 the solar powered airplane *Sunseeker* successfully flew across the USA, piloted by Eric Raymond. It used a small battery charged by solar cells on the wing to drive a propeller for takeoff, and then flew on direct solar power and took advantage of soaring conditions when possible.

The *Sunseeker II*, built in 2002, was updated in 2005-2006 with a more powerful motor, larger wing, lithium battery packs and updated control electronics. As of Dec, 2008 it was the only manned solar powered airplane in flying condition and is operated regularly by Solar Flight. In 2009 it became the first solar-powered aircraft to cross the Alps, 99 years after the first crossing of the Alps by an aircraft.

Soaring



Test Flight of *Soaring* in 1994



Summary of Configuration and Performance Parameter of "Soaring"

China's first solar powered aircraft "Soaring" was designed and built by Danny H. Y. Li and Zhao Yong in 1992. The body and wings are hand-built predominantly of carbon fiber, Kevlar and wood. The design uses winglets to increase the effective wing span and reduce induced drag.

2000s

Antares 20E

The Antares 20E is an electric, self-launching sailplane with a 42-kW DC/DC brushless motor (called EM42) and lithium-ion batteries. It can climb up to 3,000 meters with fully charged cells.

Solar Impulse

The first short-hop (350m) test flight of the Solar Impulse prototype was made on 3 December 2009.

In its present configuration it has a wingspan of 210 ft (64 m), weighs 3,500 lb (1,588 kg) and is powered by four 10-horsepower (7 kW) electric motors. The aircraft has over 11,000 solar cells on its wings and horizontal stabilizer. Power from the solar cells is stored in lithium polymer batteries and used to drive 3.5-metre (11 ft) propellers turning at a speed of 200–400 rpm. Take-off speed is 19 knots (35 km/h) and cruising speed is 60 kn (111 km/h).

The aircraft had its first high flight on 7 April 2010, when it flew to an altitude of 1,200 meters (3,937 feet) in a 1.5 hour flight on battery power alone. The Solar Impulse team is planning to use the aircraft to circumnavigate the globe in 2012.

The aircraft first flew on purely solar power, charging its batteries in flight, on 28 May 2010

On 8 July 2010 it completed the first manned 24 hour flight completely powered by solar power.

APAME Electra

The Association pour la Promotion des Aéronefs à Motorisation Électrique (APAME) (*English: Association for the Promotion of Electric Powered Aircraft*) first flew their Electra electric-powered open-cockpit airplane at 1150 hrs (local) on Sunday, 23 December 2007 at Aspres sur Buech airfield, Hautes Alpes, France. Test pilot Christian Vandamme flew the strut-equipped aircraft for 48 minutes, covering 50 km (31 miles). The Electra is powered by an 18-kW (24 hp) disk-brush electrical motor driven by a 47 kg (104 lb) lithium polymer battery power pack.

First manned AA battery powered aircraft

Matsushita Electric Industrial Co. and undergraduates at the Tokyo Institute of Technology teamed up to build an aircraft powered by 160 AA battery cells and successfully flew it for a distance of 391 meters (1,283 ft) in July, 2006.

Boeing-FCD Project



In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

The FCD (Fuel Cell Demonstrator) is a project led by Boeing that uses a Diamond Super Dimona HK-36 motor glider as a test bed for a fuel cell powered light airplane research project.

Successful test flights took place in February and March 2008.

Boeing's partners in the project are Intelligent Energy of Britain (fuel-cell); Diamond Aircraft of Austria (Airframe); Spanish Sener (control system); Spanish Aerlyper (integrate motor with airframe); Advanced Technology Products, a U.S. company (motor, batteries, flight testing).

QinetiQ Zephyr

The QinetiQ Zephyr is a lightweight solar-powered unmanned aerial vehicle engineered by the United Kingdom defence firm, QinetiQ. As of 23 July 2010 it holds the endurance record for an unmanned aerial vehicle of over 2 weeks (336 hours).

It is of carbon fiber-reinforced polymer construction, the 2010 version weighing 50 kg (110 lb) (the 2008 version weighed 30 kg (66 lb)) with a span of 22.5 metres (the 2008 version had 18 metres (59 feet)). It uses sunlight to charge lithium-sulphur batteries

during the day, which power the aircraft at night. The aircraft has been designed for use in observation and communications relay.

The 2008 Zephyr version flew for 82-hours, reaching 61,000 foot in altitude in July 2008, the then unofficial world record for the longest duration unmanned flight. In July 2010 the 2010 version of the Zephyr made a world record unmanned aerial vehicle endurance flight of 336 hours, 22 minutes and 8 seconds (more than two weeks) and also set an altitude record of 70,000 feet.

SkySpark



Skyspark in flight 2009

The SkySpark is a joint project of engineering company DigiSky and Polytechnic University of Turin. The two-seat Pioneer Alpi 300 has a 75 kW (101 hp) brushless electric motor powered by lithium polymer batteries. The aircraft achieved a world record of 250 km/h (155 mph) for a human-carrying electric aircraft on 12 June 2009.

Green Pioneer I



Test Flight of "Green Pioneer I" in 2004

The *Green Pioneer* solar powered aircraft research programme was announced at the 4th China International Aviation and Aerospace Exhibition in 2002. The experimental programme was intended to provide research data for future Chinese solar powered

aircraft. The programme was run by New Concept Aircraft (Zhuhai), the China Aviation Industry Development Research Center, and China Academy of Space Technology. The project leader and chief designer was Danny H. Y. Li.

EADS Cri-Cri

In June 2010 European aerospace company EADS unveiled an electric version of the 1970s vintage Colomban Cri-cri ultralight aircraft powered by four electric engines. The Cri-Cri will have lithium batteries and will be able to fly for 30 minutes at 60 kn (111 km/h) or 15 minutes of aerobatics at speeds up to 135 kn (250 km/h), with a climb rate of 1,000 feet per minute. The aircraft is a demonstrator for future technology, as Jean Botti, EADS's chief technical officer explained: "The Cri-Cri is a low-cost test bed for system integration of electrical technologies in support of projects like our hybrid propulsion concept for helicopters." The Cri-Cri first flew on 2 September 2010 at Le Bourget airport near Paris.

ENFICA-FC

The ENFICA-FC is a project of the European Commission, to study and demonstrate an all-electric aircraft with fuel-cells as the main or auxiliary power system. During the three year project, a fuel-cell based power system was designed and flown in a Rapid 200FC ultralight aircraft.

Design concepts

Puffin

The *Puffin* is a proposed hover-capable, electric-powered, low-noise, personal, vertical takeoff and landing (VTOL) technology-concept, proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour. Range is expected to be less than 50 miles with initial battery technology. The design has a 13.5 foot wingspan and stands 12 feet tall on the ground in its take-off or landing configuration.

As of January 2010, a one third-size, hover-capable Puffin demonstrator was planned for March 2010. Future designs might incorporate additional rotors to provide redundant systems.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for filming for the Discovery network series "Dean of Invention." The Puffin simulator was also demonstrated. The Puffin will appear in the eighth and final episode of the show.

Production aircraft

1990s

Alisport Silent Club

The first commercially available production electric aircraft was the Alisport Silent Club self-launching sailplane, first tested in 1997. It is optionally driven by a 13 kW (17 hp) DC electric motor running on 40 kg (88 lb) of batteries that provide 1.4 kWh of power.

2000s

Electraflyer

In April 2007 the Electric Aircraft Corporation began offering complete electric ultralights and engine kits under the ElectraFlyer brand name, to convert existing ultralight aircraft to electric power, in what is the first commercial offering of an electric aircraft.

The 18 hp (13 kW) engine package weighs 26 lbs and an efficiency of 90% is claimed by the company. The battery consists of two lithium-polymer battery packs which provides 1.5 hours of flying in the trike application.

In January 2008 the company introduced their new ElectraFlyer-C at the Sebring Light Sport Aircraft Show. This aircraft is a converted Monnett Moni motor glider equipped with an 18-hp electric motor, regenerative-braking-capable controller package and two lithium polymer battery packs. The engine weighs 29 lbs and the battery packs weigh 78 lbs total. The aircraft has a climb rate of 500 ft/min, cruise of 70 mph and an endurance of 90 minutes. It is capable of being recharged from a 110 volt source in six hours or from a 220 volt source in two hours. The aircraft began flying in May 2008 and was demonstrated before the crowds on August 2 at AirVenture 2008.

In April 2009 the ElectraFlyer-C prototype was offered for sale on eBay. The designer intends to use the funds from the sale, plus a Lindbergh Foundation grant of \$10,580 to complete two-place design that will eventually qualify for Light-sport aircraft status. The new design will incorporate composite construction, detachable wingtips to aid storage and will be powered by a 50 hp (37 kW) electric motor. Its design goals include a 28:1 glide ratio and a cruise speed of 80 mph (129 km/h) for two hours.

Electraflyer president Randall Fishman announced in April 2010 that the company's latest model, the Electraflyer-X, would fly in May or June 2010. The aircraft will be a two-seater and will utilize a new 20 hp (15 kW) single rotor electric powerplant. Fishman is also developing 40 hp (30 kW) two-rotor and 60 hp (45 kW) three rotor engine designs.

Sonex Aircraft

During AirVenture 2007 Sonex Aircraft announced that they are working on a series of alternate power initiatives, including an electric-powered aircraft. The electric powered Waix motor glider was first flown in December 2010 and is powered by a 54 kW (72 hp) brushless DC electric motor, managed by a newly-designed controller. Power is from a collection of 14.5 kW-hour lithium polymer batteries, giving the aircraft an endurance of one hour at low-speed cruise or 15 minutes of aerobatics.

Yuneec International E430

A new Chinese aircraft was announced in 2009. The Yuneec International E430 is a two seat, V tailed, composite aircraft with a high-aspect ratio wing. Take-off speed is 40 mph and top speed is 93 mph. The aircraft is being developed as a homebuilt aircraft for the US market.

The prototype E430 was displayed at EAA AirVenture Oshkosh in July 2009, by which time it had flown over 22 hours. The company claims that the battery packs have an expected lifespan of 1500 hours and cost US\$7000 each, with the aircraft carrying 3-5 battery packs, giving two to two and half hours endurance. The batteries can be recharged in 3 hours. The company projects that by the time the first customers require replacement battery packs that improved and less expensive ones will be available. Projected price for a commercially available light sport aircraft production version of the E430 is US\$89,000.

Flightstar e-Spyder

The e-Spyder is an electric-powered version of the Flightstar Spyder ultralight, developed by Flightstar Sportplanes president Tom Peghiny of South Woodstock, Connecticut, USA in cooperation with electric engine manufacturer Yuneec. The aircraft replaces the Spyder's two-stroke engine with a Yuneec 20 kW (27 hp) electric motor and two 28 lb (13 kg) lithium-polymer battery packs which provide a 40 minute endurance. The aircraft was exhibited at EAA AirVenture Oshkosh in July 2009 and is intended as a commercially available kit plane, forecast to be available for under US\$25,000.

Lange Antares 20E



A Lange Antares 20E in a hangar

The Lange Antares 20E is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. The motor actuates 2-blade fixed pitch propeller. It can climb up to 3,000 meters with fully charged cells. After launch it can function as a conventional, though heavy, glider. As of January 2010, over 50 had been built.

2010s

Cessna 172

In July 2010 Cessna announced it was developing an electrically-powered Cessna 172 as a proof-of-concept in partnership with Bye Energy. Cessna CEO Jack Pelton stated that the project reflects "encouraging news for the future of mainstream general aviation." Pelton pointed out "the electric power plant offers significant benefits, but there are significant challenges to get there."

PC-Aero Elektra One

The Elektra One is a development of a commercial electric aircraft design by PC-Aero of Germany. The single seat composite aircraft is expected to have its first flight in early 2011. The Elektra One is powered by a 21 hp (16 kW) electric motor and is expected to have an endurance of three hours, with a 100 mph (161 km/h) top speed.

The company is planning a whole line of aircraft including a version of the Elektra One with longer wings and built-in solar panels and an aerobatic version with double Elektra One's power and airframe strength. The company is also planning two and four seat developments.

Pipistrel Taurus Electro G2

First made available commercially in February 2011 the Taurus Electro G2 is a two-seat self-launching sailplane. The 40 kW (54 hp) engine will power the aircraft from internally-mounted lithium batteries for a 17 minute climb, after which the engine is retracted and the aircraft then soars as a sailplane.

Design and operation of electric aircraft

Regenerative flight

A design concept has been put forward for soaring-type aircraft called regenerative soaring. In this approach, a propeller, using symmetrical blade sections, would be used as a turbine to recharge stored energy when the aircraft encounters an updraft. At high altitudes, the energy available from vertical atmospheric motion within a thermal can exceed available solar power by a factor of ten or more.

Chapter 2

AeroVironment RQ-11 Raven and AeroVironment Wasp III

AeroVironment RQ-11 Raven

RQ-11 Raven UAV



Army Cpl. Jerry Rogers assembles an RQ-11
Raven unmanned aerial vehicle

Role	Remote controlled UAV
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Manufacturer	AeroVironment
First flight	October 2001
Introduction	May 2003
Status	In use on combat field
Primary users	United States Army United States Air Force
Produced	2004-present
Number built	13,000+ airframes
Developed from	FQM-151 Pointer

The AeroVironment **RQ-11 Raven** is a small hand-launched remote-controlled unmanned aerial vehicle (or SUAV) developed for the U.S. military, but now adopted by the military forces of many other countries.

The RQ-11 Raven was originally introduced as the FQM-151 in 1999, but in 2002 developed into its current form. The craft is launched by hand and powered by an electric motor. The plane can fly up to 6.2 miles (10.0 km) at up to altitudes of 10,000 feet (3,000 m) above ground level (AGL), and 15,000 feet (4,600 m) mean sea level (MSL), at flying speeds of 28-60 mph (45–97 km/h).

Design and development

The Raven RQ-11B UAV system is manufactured by AeroVironment. It was the winner of the US Army's SUAV program in 2005, and went into Full-Rate Production (FRP) in 2006. Shortly afterwards, it was also adopted by USSOCOM, the US Marines, and the US Air Force for their ongoing FPASS Program. It has also been adopted by the military forces of many other countries. More than 13,000 Raven airframes have been delivered to customers worldwide to date. A new Digital Data Link-enabled version of Raven now in production for US Forces has improved endurance, among many other improvements.

The Raven can be either remotely controlled from the ground station or fly completely autonomous missions using GPS waypoint navigation. The UAV can be ordered to immediately return to its launch point simply by pressing a single command button. Standard mission payloads include CCD color video cameras and an infrared night vision camera.

A single Raven costs about \$35,000 and the total system costs \$250,000. The RQ-11B Raven UAV weighs about 1.9 kg (4.2 lb), has a flight endurance of 60–90 minutes and an effective operational radius of approximately 10 km (6.2 miles).

The RQ-11B Raven UAV is launched by hand, thrown into the air like a free flight model airplane. The Raven lands itself by auto-piloting to a pre-defined landing point and then performing a near-vertical (1 foot down for every 1 foot forward) "Autoland" descent. The UAV can provide day or night aerial intelligence, surveillance, target acquisition, and reconnaissance.

Variants

- RQ-11A Raven A (no longer in production)
- RQ-11B Raven B
- RQ-11B eight channel
- RQ-11B DDL(Digital Data Link)

Operators



A soldier prepares to launch the Raven in Iraq



The Raven is launched.

The Raven is used by the United States Army, Air Force, Marine Corps, and Special Operations Command. Additionally, US allies such as Australia, Estonia, Italy, Denmark, Spain and Czech Republic have also begun acquiring it, with more countries expected over the next few years. As of early 2008, over 8,000 airframes have already been shipped, making it the most widely adopted UAV system in the world today.

The British forces in Iraq are using U.S. Raven equipment and personnel on loan. The Royal Danish Army acquired 12 Raven systems in September 2007 - three systems will be delivered to the Huntsmen Corps, while the remainder will be deployed with soldiers from the Artillery Training Center.

The Netherlands MoD has acquired 72 operational RQ-11B systems with a total value of \$23.74 million for use within Army reconnaissance units, its Marine Corps and its Special Forces (KCT). At the turn of the year 2009 to 2010 the systems were deployed above the village Veen, as part of the Intensification of Civil-Military Cooperation.

Current operators

-  Australia
-  Czech Republic

-  Denmark
-  Estonia
-  Spain
-  Iraq
-  Italy
-  Lebanon 12 systems
-  Netherlands
-  Norway
-  United Kingdom
-  United States

Specifications

- Wing Span 55in (130 cm)
- Length 36in (109 cm)
- Weight 4.2 lb (1.9 kg)
- Engine Aveox 27/26/7-AV electric motor
- Cruising speed approx. 30 kn (56 km/h)
- Range 6.2 miles (10 km)
- Endurance approx. 60-90 min

AeroVironment Wasp III

Wasp III Small Unmanned Aircraft System



Role	Remote controlled UAV
Manufacturer	AeroVironment Inc.
Introduction	2007
Primary user	United States Air Force
Unit cost	\$49,000

The **Wasp III Small Unmanned Aircraft System** is an unmanned aerial vehicle (UAV) developed for United States Air Force special forces to provide a small, light-weight

vehicle to provide beyond-line-of-sight situational awareness. The aircraft is equipped with two on-board cameras to provide real-time intelligence to its operators. It is also equipped with GPS and an Inertial Navigation System enabling it to operate autonomously from takeoff to recovery. It was designed by AeroVironment Inc. and was first added to the Air Force inventory in 2007. There are two Wasp variants: the traditional version that lands on land ("Terra Wasp") and a version that lands into the sea or fresh water ("Aqua Wasp").

Operators

 United States

- **United States Air Force**
- **United States Marine Corps**

 France

- **French Navy**

 Australia

- **Australian Army**

Specifications

General characteristics

- **Crew:** none
- **Length:** 1.25 ft (38 cm)
- **Wingspan:** 2.375 ft (72.3 cm)
- **Height:** ()
- **Empty weight:** 0.95 lb (430 g (Land version))
- **Loaded weight:** 14.4 lbs (6.53 kg)
- **Powerplant:** 1× Electric motor, rechargeable lithium ion batteries, ()

Performance

- **Maximum speed:** 40mph 65 km/h
- **Cruise speed:** 40 - 65 km/h
- **Range:** 5 km ()

Armament

High resolution, day/night cameras with digital image stabilization and digital pan/tilt/zoom

Chapter 3

ElectraFlyer, Lange Antares 20E and Puffin (Aircraft)

ElectraFlyer

ElectraFlyer

Role	ultralight aircraft
Manufacturer	Electric Aircraft Corporation
Designed by	Randall Fishman
First flight	April, 2007
Primary user	Private individuals
Produced	2007–Present
Unit cost	\$16,000-\$21,000

The **ElectraFlyer** trike is an ultralight aircraft that flies using an electric motor, instead of a traditional gasoline engine.

The ElectraFlyer-C is a prototype aircraft that uses the same electric motor configuration as the ElectraFlyer Trike.

Specifications

The Electraflyer Trike is built to comply with Federal Aviation Regulations, part 103. The standard ElectraFlyer is equipped with a 5.6—kWh Lithium-ion polymer battery which powers an 18 hp electric motor — which can be optionally upgraded to a 40 hp motor. Depending on the number of battery packs attached, the aircraft can fly for between one and two hours before it must be recharged for 5–6 hours using a standard 120 volt AC outlet. Charging time can be reduced to 2 hours using a 240 volt outlet.

Mounting a Stratus-model Rogallo wing design, the total aircraft weight is less than 249 pounds, depending on the options selected for engine, batteries, and other accessories such as a ballistic parachute.

It was awarded the Grand Champion Ultralight at the 2007 EAA AirVenture Oshkosh Fly-In.

The ElectraFlyer-C is a converted metal Monnett Moni motoglider equipped with the same power plant as the Electraflyer Trike. This airplane cruises at 70 mph (113 km/h), stalls at 45 mph (72 km/h) and has a top speed of 90 mph (145 km/h) with a flight duration of 1½ to 2 hours and a climb rate of 500 to 600 fpm (2.5 – 3 m/s).

Lange Antares 20E

Antares 20E



Lange Flugzeugbau Antares 20E

Role	Open Class sailplane
National origin	Germany
Manufacturer	Lange Aviation GmbH
First flight	2003
Number built	50 as of April 2009

The **Antares 20E** is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. It can climb to 3,000 meters on one battery charge.

The EM 42 is a fixed-shaft brushless DC electric motor running at 190-288 V, and drawing up to 160 A, the 42 kW motor can deliver up to 216 N.m of torque over a speed range of 160-1600 RPM with a total efficiency of 90%. Maximum continuous power is 38.5 kW, the motor weighs 29 kg, and the weight of power electronics is 10 kg. The motor turns a 2-blade fixed-pitch propeller LF-P42 constructed of composite materials with 2.00 m diameter.

The battery system consists of two battery packs positioned in the leading edges of both inner wings (72 cells divided into 24 modules containing 3 cells each). The battery life is expected to 3000 cycles or 20 years. Capacity of battery is 41 Ah (specific energy 136 Wh/kg and specific peak power 794 W/kg). The batteries can deliver 13 minutes at maximum power and maximum climb speed. The charger is integrated inside the fuselage so when landing elsewhere the pilot merely has to find an electric outlet socket. The glider has a modem connected to its main computer so that technicians can run diagnostics remotely.

The undercarriage is hydraulically operated. The tailwheel is steerable.

Specifications

General characteristics

- **Crew:** one pilot
- **Capacity:** 100 l water ballast
- **Length:** 7.40 m (24 ft 3 in)
- **Wingspan:** 20.00 m (65 ft 7 in)
- **Height:** 1.64 m (5 ft 5 in)
- **Wing area:** 12.6 m² (135.6 ft²)
- **Aspect ratio:** 31.7
- **Empty weight:** 460 kg (1 014 lb)
- **Gross weight:** 660 kg (1 455 lb)
- **Powerplant:** 1 × EM42 (brushless DC electric motor), 42 kW (57 hp)

Performance

- **Maximum speed:** 280 km/h (174 mph)
- **Maximum glide ratio:** 56
- **Rate of climb:** 4.4 m/s (866 ft/min)
- **Rate of sink:** 0.49 m/s (96 ft/min)

Puffin

The **Puffin** is a proposed hover-capable, electric-powered, low-noise, personal vertical takeoff and landing (VTOL) technology-concept proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour (241 km/h). Range is expected to be less than 50 miles (80 km) with 2010-vintage Lithium-iron-phosphate battery technology. The design has a 13.5 foot (4.1 m) wingspan and stands 12 feet (3.65 m) tall on the ground in its take-off or landing configuration.

Development

As of January 2010, NASA expected to achieve the first flight of a one-third scale, hover-capable Puffin demonstrator by March 2010. By mid-summer 2010, they hoped to "begin investigating how well it transitions from cruise to hover flight.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for the filming of the Discovery network series "Dean of Invention." The Puffin simulator was also demonstrated. The Puffin is slated to appear in the eighth and final episode of the show.

Chapter 4

Avro 720 and Blohm & Voss P.194

Avro 720

	Avro 720
Role	Interceptor
National origin	United Kingdom
Manufacturer	Avro
Status	Cancelled before completion of first prototype
Number built	0

The **Avro 720** was a planned British single-seat interceptor of the 1950s. It was to be of mixed propulsion, with a rocket engine to give high performance and a small jet engine for cruising flight. At least one prototype was ordered, but the project was cancelled before any were completed.

Design and development

In the early 1950s, the British Air Ministry, impressed by the performance of the rocket-powered Messerschmitt Me 163 fighter, and facing the potential threat of Soviet supersonic bombers armed with nuclear weapons, issued Specification F.124T for a rocket powered point-defence interceptor. This was to be of similar concept to the Me 163, using its rocket to climb rapidly to meet its target, before gliding back to earth, fuel exhausted, to land on a retractable skid. Proposals to meet the specification were received from a number of companies, including Avro, Bristol, Blackburn, Shorts and Saunders-Roe. It was soon realised, however, that a rocket-only fighter with the performance required by the specification, which would have to glide back to ground from heights of up to 100,000 ft (30,500 m), land without power many miles away and then be recovered and taken back to the airfield by ground vehicle, was impracticable. Revised specifications were therefore issued to Avro and Saunders-Roe for aircraft with auxiliary turbojet engines, giving sufficient power to allow the aircraft to fly back to its airbase after combat.

Avro's design, the Avro Type 720, designed to meet specification F.173D, was a small tailless delta-winged aircraft. It was constructed of metal honeycomb sandwich. The main power-plant was an 8,000 lbf (36 kN) Armstrong Siddeley Screamer rocket engine, using liquid oxygen as oxidant and kerosine fuel. This differed from the competing Saunders-Roe SR.53, which used a de Havilland Spectre powered by Hydrogen Peroxide and kerosine. Both types used a 1,750 lbf (7.8 kN) Armstrong-Siddeley Viper as the auxiliary turbojet, with the Avro design fed with air from a small chin inlet under the aircraft's nose. Two de Havilland Firestreak Infrared homing air-to-air missiles could be carried on underwing pylons.

Two prototypes were ordered, and the Screamer engine successfully completed flight clearance tests in December 1956. Official concern about the practicality of using liquid oxygen, which boils at -183°C (90 K), in an operational environment led to the Screamer engine being cancelled late in 1956, together with the Avro 720. One structural test airframe was part complete at the time of cancellation, and photographs of this airframe, with the port wing fitted and the serial number *XD696* painted on are sometimes claimed to be the "almost complete" first prototype. The Avro 720 had cost £1 Million by the time of cancellation, while its Screamer powerplant cost a further £0.65 million.

Specifications (Performance estimated)

General characteristics

- **Crew:** 1
- **Length:** 42 ft 3 in (12.88 m)
- **Wingspan:** 27 ft 3.5 in (8.319 m)
- **Wing area:** 166 sq ft (15.4 m²)
- **Empty weight:** 7,812 lb (3,543 kg)
- **Max takeoff weight:** 17,575 lb (7,972 kg)
- **Powerplant:** 1 × Armstrong Siddeley Screamer liquid-fuelled rocket, 8,000 lbf (36 kN) thrust
- **Powerplant:** 1 × Armstrong Siddeley Viper ASV.8 turbojet, 1,750 lbf (7.8 kN) thrust

Performance

- **Maximum speed:** 1,320 mph (2,120 km/h; 1,150 kn) at 40,000 ft (12,200 m)
- **Maximum speed:** Mach 2.0
- **Service ceiling:** 60,000 ft (18,288 m)
- **Time to altitude:** 1 min 50 s to 40,000 ft (12,200 m)

Armament

- **Missiles:** Provision for 2× de Havilland Firestreak infra-red homing air-to-air missiles

Blohm & Voss P.194

P.194



Model photo of a Blohm & Voss BV P.194.02

Role	Tactical bomber
National origin	Germany
Manufacturer	Blohm & Voss
Designed by	Richard Vogt
Status	Unrealised project

The **Blohm & Voss P.194** was a design for a mixed-power ground-attack aircraft and tactical bomber developed in Germany during World War II. Like some of Richard Vogt's other designs for Blohm & Voss, the P.194 featured an asymmetric layout.

Along with the P.192, P.193, and P.196, the P.194 was one of four designs Blohm & Voss submitted in response to a requirement issued by the RLM in February 1944 for a replacement for the venerable Junkers Ju 87. The basic design of the aircraft echoed that of the BV 141: the crew and weapons carried in a nacelle separate from the main fuselage structure that carried a propeller-driven engine at one end and the empennage at the other, joined together by a common wing. In the P.194, however, a turbojet was to be added at the rear of the cockpit pod and the design intended that the thrust from this engine would help balance the thrust from the propeller. A powerful cluster of guns was to be located in the nose, and a bombload of up to 500 kg (1,100 lb) was to be carried in an internal bomb bay in the fuselage.

All four Blohm & Voss designs were rejected by the RLM, which instead selected the Messerschmitt Me 262 to fill the tactical bomber role instead.

Design stages

- **P.194.00-101** - version with 16 m (52 ft) wingspan and jet intake under cockpit pod
- **P.194.01-02** - version with 15.3 m (50.2 ft) wingspan, bubble canopy and jet intake under cockpit pod
- **P.194.02-01** - as above, but with turbojet located beneath cockpit
- **P.194.03-01** - as P.194.01-02, but with jet intakes located in the wing roots at the sides of the cockpit pod.

Specifications (194-01, as designed)

General characteristics

- **Crew:** One pilot
- **Length:** 12.10 m (39 ft 8 in)
- **Wingspan:** 15.30 m (50 ft 2 in)
- **Height:** 3.70 m (12 ft 2 in)
- **Wing area:** 36.4 m² (391 ft²)
- **Empty weight:** 6,500 kg (14,300 lb)
- **Gross weight:** 9,350 kg (20,600 lb)
- **Powerplant:** 1 × BMW 801D, 1,200 kW (1,600 hp)

1 × Junkers Jumo 004, 8.7 kN (2,000 lbf) thrust

Performance

- **Maximum speed:** 775 km/h (484 mph)
- **Range:** 1,070 km (669 miles)
- **Service ceiling:** 11,100 m (36,400 ft)

Armament

- 2 × fixed, forward-firing 30 mm (1.18 in) MK 103 cannons
- 2 × fixed, forward-firing 20 mm MG 151/20 cannons
- 500 kg (1,102 lb) of bombs in internal bay

Chapter 5

Curtiss XF15C and Focke-Wulf Ta 400

Curtiss XF15C

XF15C

Role	Fighter
National origin	United States
Manufacturer	Curtiss Aeroplane and Motor Company
First flight	27 February 1945
Number built	3

The **Curtiss XF15C** was a mixed-propulsion fighter prototype of the 1940s.

Development

By the late 1940s, the United States Navy was interested in the mixed-power concept for its shipborne fighters - i.e. aircraft with a mixture of propellor and turbojet engines, such as the FR Fireball. As such, an order was placed with Curtiss on 7 April 1944 for delivery of three mixed-power aircraft, designated the F15C. Powered by both a 2,100 hp (1,566 kW) Pratt & Whitney propellor engine, and an Allis-Chalmers J36 turbojet, the aircraft was in theory the fastest fighter in the US Navy at that time.

Operational history

The first flight of the first prototype was on 27 February 1945, without the turbojet installed. When this was completed in April of the same year, the aircraft flew several mixed-power trials, however on May 8 it crashed on a landing approach. The second prototype flew for the first time on 9 July, again in 1945, and was soon followed by a third prototype. Both aircraft showed promise, however by October 1946 the Navy had lost interest in the mixed-power concept and cancelled further development.

Specifications

General characteristics

- **Crew:** 1
- **Length:** 44 ft 0 in (13.41 m)
- **Wingspan:** 48 ft 0 in (14.63 m)
- **Height:** 15 ft 3 in (4.65 m)
- **Wing area:** 37.16 ft² (400 m²)
- **Empty weight:** 12,648 lb (5,739 kg)
- **Gross weight:** 16,630 lb (7,543 kg)
- **Powerplant:** 1 × Pratt & Whitney R-2800-34W 18-cylinder two-row radial, 2,100 hp (1,566 kW)

1 × Allis-Chalmers J36 turbojet, 2,700 lbf (1,226 kN) thrust

Performance

- **Maximum speed:** 469 mph (755 km/h)
- **Range:** 1,385 miles (2,228 km)
- **Rate of climb:** 5,020 ft/min (25.5 m/s)

Armament

- 4 × wing-mounted 20 mm (.79 in) cannon

Focke-Wulf Ta 400

Ta 400

Role	Amerika Bomber
Manufacturer	Focke-Wulf
Designed by	Kurt Tank
Primary user	<i>Luftwaffe</i>
Number built	1 prototype, never completed

The **Focke-Wulf Ta 400** was a large six-engined bomber prototype developed in Nazi Germany in 1943 by Focke-Wulf as a serious contender for the Amerika Bomber project. One of the first aircraft to be developed from components from multiple countries, it was also one of the most advanced Focke-Wulf designs of World War II, though it never progressed beyond a wind tunnel model.

Designed as a bomber and long-range reconnaissance plane by Kurt Tank, the Ta 400 had a shoulder-mounted wing with 4° dihedral. One of the most striking features was the six BMW 801D radial engines, to which two Jumo 004 jet engines were later added.

Design and development

In response to the RLM guidelines of 22 January 1942, Kurt Tank of the Focke-Wulf company designed the Ta 400 as a bomber and long-range reconnaissance aircraft to be powered by six BMW 801D radial engines, to which two Jumo 004 jet engines were later added. Design work was begun in 1943, much of it being carried out by French technicians working at Châtillon-sous-Bagneux near Paris, with contracts for design and construction of major components being awarded to German, French, and Italian companies in an attempt to speed the process and begin construction of prototypes as soon as possible.

The Ta 400 had a shoulder-mounted wing with 4° dihedral, with a long straight center section extending to the middle engine on each wing, and highly tapered outer wing panels. It had twin vertical stabilizers mounted at the tips of the tailplane. Like the American Boeing B-29 Superfortress the Ta 400 was to have a pressurized crew compartment and tail turret, connected by pressurized tunnel, as well as multiple remote-controlled turrets. The crew of nine was to be protected by a heavy defensive armament including ten 20 mm MG 151 cannons. The Ta 400 was to use a staggering 32 fuel tanks. Another design feature was tricycle landing gear.

Maximum bomb load was to be 24 t (53,000 lb). With a gross weight of 80.27 tonnes (88.48 short tons), the Ta 400 with DB 603 engines was estimated to have a range of 12,000 km (7,500 mi) in the reconnaissance role, cruising at 325 km/h (202 mph). The two bomber versions would have 76.07 tonnes (83.85 short tons) and 80.87 tonnes (89.14 short tons) gross weights with estimated ranges of 4,500 km (2,800 mi) and 10,600 km (6,600 mi) respectively. The projected Jumo-powered aircraft would have had a maximum range of 14,000 km (8,700 mi) for long range reconnaissance and 13,000 km (8,100 mi) as a bomber. Because no prototype was ever built, it never progressed beyond a wind tunnel model, and performance, range and dimensions are based solely on the designers' estimates.

The Ta 400 was essentially a backup design for the Messerschmitt Me 264. As the design required more materials and labor than the Me 264, the RLM became convinced that further development of the Ta 400 was a waste and on 15 October 1943, notified Focke-Wulf that the program would be terminated, but the minutes of a meeting in Italy of Tank with Italian aviation industrialists on 18 April 1944 confirmed that the design was still active and proposed the cooperation of Italian industry to the project.

Specifications

General characteristics

- **Crew:** 6
- **Length:** 28.7 m (94 ft 2 in)
- **Wingspan:** 45.8 m (150 ft 3 in)
- **Height:** ()
- **Loaded weight:** 60,000 kg (132,000 lb)
- **Powerplant:**
 - 2× Junkers Jumo 004 turbojets, 1,980 lbf (8.8kN) each
 - 6× BMW 801D radials, 1,700 hp (1.3 MW) each

Performance

- **Maximum speed:** 343 knots (395 mph, 635 km/h)
- **Range:** 4,860 nmi (5,592 mi, 9,000 km)

Armament

- **Guns:** 10 × MG 151/20 in five twin turrets
- **Bombs:** 22,046 lb / 10,000 kg total

Chapter 6

Gulfstream American Hustler and McDonnell XF-88 Voodoo

Gulfstream American Hustler

Hustler

Role	Executive or utility aircraft American Jet
Manufacturer	Industries/Gulfstream American
First flight	1978
Number built	1

The **Gulfstream American Hustler** was a 1970s American mixed-power executive/utility aircraft designed by American Jet Industries (later Gulfstream American). The aircraft had a nose-mounted turboprop and with a tail-mounted turbofan.

Development

In 1974, American Jet Industries started work on a seven-seat executive transport with a Pratt & Whitney Canada PT6 engine in the nose supplemented by a Williams Research Corporation WR19-3-1 turbofan mounted in the tail. The turbofan was originally intended to be a standby emergency power unit that could also be used if extra thrust was needed for take-off. The prototype designated **Hustler 400** (*N400AJ*) first flew on the 11 January 1978. The Hustler was a low-wing cantilever monoplane with retractable tricycle landing gear, and a high-mounted tailplane.

It was originally intended to be certified as a single-engined aircraft because the Williams turbofan had not been certified. But the company (by then called Gulfstream American) decided it should be approved as a twin and the Williams turbofan was replaced with a Pratt & Whitney Canada JT15D turbofan. To enable the engine to be fitted a 2 ft 8 in (0.81m) extension to the forward fuselage. The cabin entrance door was moved in front of the wing and other aerodynamic changes. The intake for the rear engine was also moved from the lower rear fuselage to the base of the fin.

Another change was made in 1979 when the front engine was replaced by a Garrett TPE331 turboprop and the aircraft was re-designated the '*Hustler 500*'. The aircraft was flown in this configuration in 1981 but the programme was suspended due to a recession in the general aviation market. Elements for the design were used in the prototype jet trainer the Peregrine 600.

Variants

Hustler 400

Prototype mixed-power aircraft with a Pratt & Whitney Canada PT6A-41 in the nose.

Hustler 500

Modified aircraft with a Garrett TPE331 Turboprop in the nose.

Specifications (*Hustler 500*)

General characteristics

- **Crew:** One
- **Capacity:** Four or five passengers
- **Length:** 41 ft 3 in (12.57 m)
- **Wingspan:** 34 ft 5 in (10.49 m)
- **Height:** 13 ft 2½ in (4.03 m)
- **Wing area:** 190.71 ft² (17.72 m²)
- **Empty weight:** 5430 lb (2463 kg)
- **Gross weight:** 10,000 lb (4536 kg)
- **Powerplant:** 1 × Garrett TPE331-10-501 turboprop, 900 hp (671 kW)

1 × Pratt & Whitney Canada JT15D-1 turbofan, 2,200 lbf (kN) thrust

Performance

- **Maximum speed:** 402 mph (647 km/h)
- **Range:** 2303 miles (3706 km)
- **Service ceiling:** 38,000 ft (11580 m)

McDonnell XF-88 Voodoo

XF-88 Voodoo



Role	Escort fighter
Manufacturer	McDonnell
First flight	20 October 1948
Status	Cancelled
Primary user	United States Air Force
Number built	2
Program cost	US\$6.6 million
Developed into	F-101 Voodoo

The **McDonnell XF-88 Voodoo** was a long-range, twin-engine jet fighter aircraft designed for the United States Air Force. Although it never entered service, its design was adapted for the subsequent F-101 Voodoo.

Design and development

The XF-88 originated from a 1946 United States Army Air Forces requirement for a long-range 'penetration fighter' to escort bombers to their targets. It was to be essentially a jet-powered replacement for the wartime P-51 Mustang that had escorted B-17 Flying Fortress bombers over Germany. It was to have a combat radius of 900 mi (1,450 km) and high performance. McDonnell began work on the aircraft, dubbed **Model 36**, on 1 April 1946. On 20 June the company was given a contract for two prototypes designated **XP-88**. Dave Lewis was Chief of Aerodynamics on this project.



The engineering team stands after Flight 100



Supersonic jet-turboprop hybrid XF-88B



Landing the XF-88

The initial design was intended to have a V-shaped tail, but wind tunnel tests indicated aerodynamic problems that led to an extensive redesign. The USAAF (which became the United States Air Force on 17 September 1947) approved the changes. When the USAF altered its designation scheme in 1948, the still unflown prototypes were redesignated **XF-88**. It was dubbed **Voodoo**.

The Voodoo had a low/mid-mounted wing, swept to 35°. The two engines were in the lower fuselage, with jetpipes beneath the rear fuselage. The prototypes carried XJ34 engines, although the production **F-88A** would have had two Westinghouse J46 turbojets with 5,920 lbf (26.33 kN) each. Intakes were mounted in the wing roots. The Voodoo's short nose had no radar, being intended to house an armament of six 20 mm (.79 in) M39 cannon.

The first XF-88 made its maiden flight on 20 October 1948. It had non-afterburning engines and no armament. It proved to be underpowered, leading to the decision to install afterburners on the second prototype, which was designated **XF-88A** and made its first flight on 26 April 1949. (The first prototype was modified to the same standard.)

In a subsequent paper competition against the Lockheed XF-90 and North American YF-93, the Voodoo lost to the XF-93, but the decision on production was later delayed until a 'fly-off' competition could be held. In that fly-off, held in the summer of 1950, the XF-88 proved the winner, but changes in Air Force requirements led the penetration fighter to be cancelled entirely.

McDonnell proposed a naval version of the XF-88, a two-seat operational trainer, and a reconnaissance variant, but none were built. The first prototype was modified to **XF-88B** standard, with a nose-mounted Allison T38 turboprop engine added to the two existing turbojets. This was used for flight testing through 1956, and achieved speeds slightly exceeding Mach 1.0, the first propeller-equipped aircraft to do so. Both prototypes were scrapped by 1958.

A considerably enlarged version of the basic design was developed following the cancellation of the XF-88, becoming the F-101 Voodoo, the first production version of which flew on 29 September 1954. The basic layout of two engines under the tail would also appear in the redesign of an upgraded F3H Demon which would see service as the very successful F-4 Phantom II.

Operators

 United States

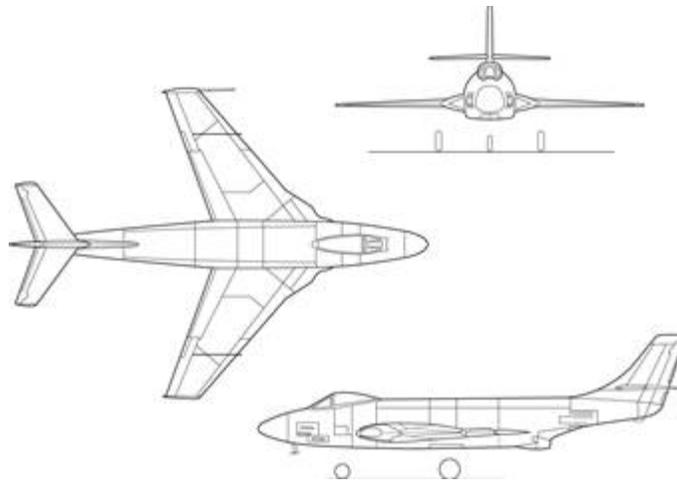
- United States Air Force

Variants

XF-88A

XF-88B

Specifications (XF-88A)



General characteristics

- **Crew:** one
- **Length:** 54 ft 1.5 in (16.5 m)
- **Wingspan:** 39 ft 8 in (12.1 m)
- **Height:** 17 ft 3 in (5.3 m)
- **Wing area:** 350 ft² (32.5 m²)
- **Empty weight:** 12,140 lb (5,508 kg)

- **Loaded weight:** 18,500 lb (8,394 kg)
- **Max takeoff weight:** 23,100 lb (10,477 kg)
- **Powerplant:** 2× Westinghouse J34-WE-22 afterburning turbojets, 4,825 lbf (21.4 kN) each

Performance

- **Maximum speed:** 706 mph (1,130 km/h)
- **Range:** 1,737 mi (2,779 km)
- **Service ceiling:** 39,400 ft (12,012 m)
- **Rate of climb:** 8,000 ft/min (40 m/s)
- **Wing loading:** 52.9 lb/ft² (258 kg/m²)
- **Thrust/weight:** 0.44

Armament

- 6 × 20 mm (.79 in) M39 cannon

Chapter 7

Mikoyan-Gurevich I-250

I-250



An I-250 showing its motorjet exhaust

Role	Fighter aircraft
Manufacturer	Mikoyan-Gurevich
First flight	3 March or 4 April 1945
Status	Cancelled
Produced	1945–1946
Number built	12

The **Mikoyan-Gurevich I-250** (a.k.a. *Samolet N*) was a Soviet fighter aircraft developed as part of a crash program in 1944 to develop a high-performance fighter to counter German turbojet-powered aircraft such as the Messerschmitt Me-262. The Mikoyan-Gurevich design bureau decided to focus on a design that used something more mature than the jet engine, which was still at an experimental stage in the Soviet Union, and chose a mixed-power solution with the VRDK motorjet powered by the Klimov VK-107 V12 engine. While quite successful when it worked, with a maximum speed of 820 km/h (510 mph) being reached during trials, production problems with the VRDK fatally delayed the program and it was canceled in 1948 as obsolete.

Design and development

By January 1944 the Soviets were aware of successful British and American jet aircraft projects and that the Germans were about to deploy jet and rocket-propelled aircraft of their own. The GKO ordered on 18 February that the NKAP (People's Commissariat for Aviation Industry) centralize jet research under its control and that the NKAP was to present proposals to alleviate the situation within a month. As a result of this meeting the NKAP ordered the Lavochkin, Sukhoi, Yakovlev and Mikoyan-Gurevich design bureaux (OKBs) to develop and build jet aircraft with the utmost dispatch. Aware of earlier problems encountered with other novel propulsion systems such as ramjets both Sukhoi and Mikoyan-Gurevich chose to use the VRDK (*Vozdushno-Reaktivnyy Dvigatel' Kompessornyy* — Air-reactive compressed engine) jet booster engine that had been under development since 1942.

The VRDK was a motorjet, a rudimentary type of jet engine where an external power source drove the engine's compressor. It forced air into the stainless steel combustion chamber where fuel was sprayed from seven nozzles and ignited to exhaust out the variable rear nozzle. In the I-250 a 1,650-horsepower (1,230 kW) Klimov VK-107R V-12 piston engine was used as the primary powerplant. After takeoff a clutch at the end of the crankshaft could be engaged which drove a step up gearbox with a ratio of 13:21 to an extension shaft that powered the compressor of the VRDK. The air for the compressor was fed through a long duct that ran from the inlet underneath the propeller spinner, thence under the engine and through the belly of the aircraft. This duct also fed air to the oil cooler near the engine, but the water radiator was positioned behind the compressor to maximize airflow over it. A secondary duct led from the main duct to the VK-107's supercharger; when the VRDK was running the secondary duct diverted some of that additional air to the supercharger which boosted the engine's output to 2,500-horsepower (1,900 kW) at 7,000 m (22,966 ft). The increased airflow over the engine radiator helped to dump the engine's excess heat into the exhaust stream. However the VRDK was limited to only ten minutes' operating time per sortie, which meant that it was useless weight during the rest of the flight.

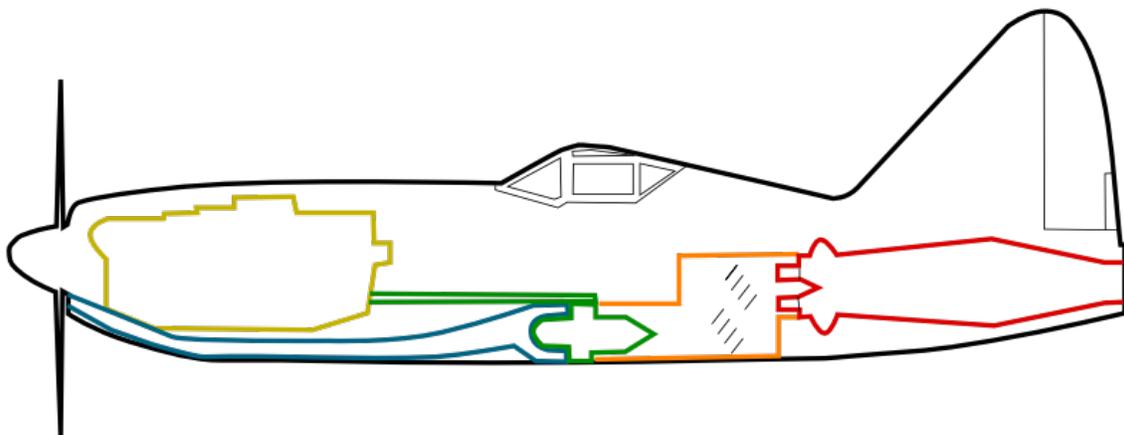


Diagram of the I-250's engine installation

The I-250 was a low-wing, all-metal aircraft with a monocoque fuselage. Other than the VRDK the aircraft was largely conventional in layout, although the cockpit was set very far back in the fuselage, almost to the base of the vertical tail. The two-spar wings had a thickness of 10% to preserve aileron control and avoid tip stall. They were fitted with Frise ailerons and slotted flaps. Fuel was contained in a 412-litre (91 imp gal; 109 US gal) fuselage tank and a 100-litre (22 imp gal; 26 US gal) tank in each wing. The conventional landing gear mainwheels had a levered suspension and retracted inwards. The tail wheel retracted aft into the very small ventral fin. The VK-107A engine initially drove a 3.1-metre (10 ft) VISH-105SV propeller.

The NKAP had asked Mikoyan to begin preliminary design work on a high-altitude interceptor in January 1944, but ordered two prototypes of an all-metal interceptor using the VRDK for testing in February and March 1945. The aircraft was to reach an altitude of 5,000 m (16,000 ft) in 4.5 minutes with full power and 5.5 minutes using the piston engine alone. Its maximum speed was to be 810 km/h (500 mph) at 7,000 m (22,966 ft) with full power and 700 km/h (430 mph) at 7,000 m (22,966 ft) using the VK-107 by itself. Its intended armament was one 23 mm (0.91 in) autocannon and two 12.7 mm (0.50 in) machine guns. To assist Mikoyan TsAGI was ordered to provide help with aerodynamic and stress calculations and to test a full-size mockup in their wind tunnel in one month's time. TsIAM was ordered to deliver three VRDK engines with 9-kilonewton (2,000 lbf) at 7,000 m (22,966 ft) with a specific fuel consumption of 1,200 kg (2,600 lb) per hour. The plane was designated **I-250** by the NKAP; but the internal OKB designation was **N**.

The NKAP approved the preliminary specifications of the I-250 on 19 September 1944 which included a maximum speed of 825 km/h (513 mph) a take-off weight of 3,500 kg (7,700 lb) and a time to 5,000 metres (16,404 ft) of 3.9 minutes. A mock-up was inspected on 26 October and rejected because of the poor cockpit layout, although this decision was reversed because the fuselage of the first prototype was too far along for major changes that would have significantly delayed the program. That same month the combustion chamber was sent to TsIAM for testing which revealed it to be too weak. The complete powerplant was tested in December, but the drive shaft connecting them failed several times.

The first prototype was completed on 26 February 1945, although the VRDK was not yet ready. It was fitted with a new 3.1-metre (10 ft) AV-10P-60 propeller before making its first flight on 4 April according to Gordon and Komissarov, although Belyakov and Marmain say 3 March. It was armed with three 20 mm Berezin B-20 cannon with 160 rounds each. One gun was fitted on each side of the nose and the third fired through the hollow propeller shaft. The VRDK was tested for the first time on 8 April in a dive, attaining a speed of 710 km/h (440 mph), but a leak was found in the oil cooler after landing and the VRDK had to be returned to the factory for repairs. The VRDK was reinstalled by 14 April, but was still troublesome. It twice reached 809 km/h (503 mph) at about 7,000 m (22,966 ft) during these early tests, but its service life had been exceeded by 30 May and it had to be returned to TsIAM, which postponed any further tests until the second aircraft was finished.

The unarmed second prototype was completed on 19 May, but did not make its first flight until 26 May. It was later discovered to have several major defects, including an oil leak from the VRDK compressor's sleeve. The VRDK's designer was summoned in an attempt to solve its problems although not all of these were design issues. The first prototype was grounded for most of June to remedy magneto problems and to add extra air intakes to cool the spark plugs. It attained a speed of 820 km/h (510 mph) at 6,700 m (21,982 ft) on 3 July. Unfortunately its port tailplane failed at low altitude two days later, killing the test pilot, Alexandr Deyev, when his parachute failed to open in time. Post-crash analysis revealed that he had exceeded the airframe's G limit while maneuvering.

Despite the accident, a pre-production batch of ten aircraft was ordered on 27 July 1945 as it was felt that mixed-power aircraft would be of some use easing the transition of pilots from piston-engine fighters to jet-engined ones. At the same time Sukhoi's Su-5 was cancelled as it was judged inferior to the I-250.

In the meantime the horizontal stabilizer of the second prototype was strengthened and it resumed flying on 20 July. The pilot complained of excess torque pull to the right so the vertical stabilizer was enlarged by 0.63 m² (6.8 sq ft), but this was just one of numerous problems, and it was not ready to pass State acceptance trials without more development work on the powerplant. However, the second prototype continued flight testing until 12 July 1946 when an engine fire forced an emergency landing and it was damaged beyond repair.

The order for the pre-production I-250s had been placed with Factory No. 381 in Moscow for two aircraft to be delivered in September, three more in October and the remainder by the end of the year. This proved to be very optimistic and it was revised to a single aircraft by the end of the year. The airframe was completed on this revised schedule, but its engine was not ready in time. The factory management was much criticized for these problems which were not entirely under their control as changes to the design and drawings were constant. The criticism was not limited to just the I-250 program as the other jet programs could not be developed as fast as the leadership wanted as well and Alexei Shakhurin, the head of MAP (Ministry of Aviation Industry) and its NKAP predecessor since 1940, was arrested in March 1946 as a sign of their displeasure. The new Minister severely reprimanded the designer of the VRDK and three factory directors on 13 April 1946 and set up a commission to determine why Factory No. 381 and TsIAM had failed to meet their deadlines. He refused to accept its findings as it apportioned blame fairly evenly among those responsible for the production program and he had the director of Factory No. 381 and his quality control manager arrested for industrial sabotage.

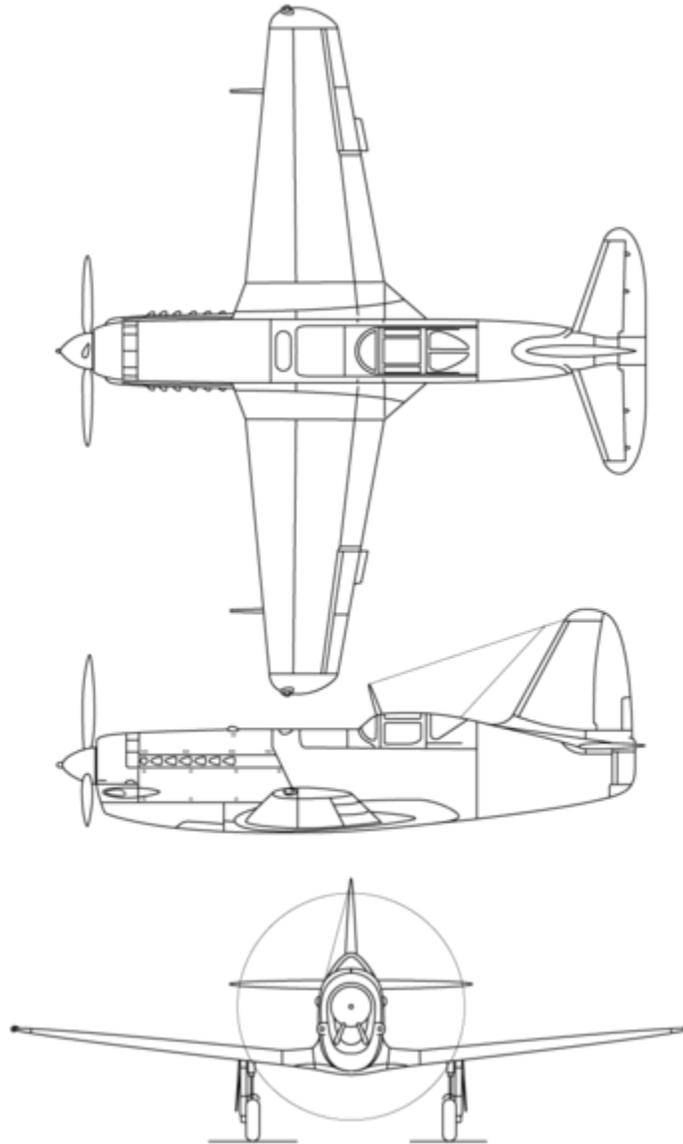
Despite these production problems and the fact that the I-250 had yet even to be submitted for State acceptance trails, an order had been placed for fifty more aircraft on 26 February (these aircraft have been referred to as the **MiG-13**, which presumably would have been their designation if they had actually entered service). A new deadline of 5 July 1946 was set for the delivery of the first pre-production aircraft, but it was stymied, again, for a lack of an engine. By this time seven airframes had been completed,

but all lacked engines. The first I-250 was finally accepted on 8 August and flown for the first time three days later, although its engine seals failed and a number of ignition cables were scorched. The engine replacement and repairs forced the aircraft to miss its scheduled appearance at the Tushino Air Display. It was handed over to the NII VVS (Air Force Institute) on 15 September to finally begin its State acceptance tests. All ten aircraft had been delivered by 30 October, although construction number 3810107 (Factory No. 381, first batch, seventh aircraft) was used as a static test airframe and 3810110 became a static engine testbed.

Stalin convened a meeting on 29 November 1946 to settle the future policy on jet fighters for the VVS and PVO. The Mikoyan-Gurevich MiG-9 was selected as the primary fighter with the Yakovlev Yak-15 relegated to conversion training and familiarization. The imminent availability of British jet engines and access to German jet technology and engineers meant that there was no longer any need for mixed-power aircraft, but Stalin insisted that the I-250 finish its trials and that the tooling and drawings should be retained along with unassembled parts even though the program was cancelled.

Completion of the trials would be delayed until May 1947 when the trials of the VRDK itself would be completed and Mikoyan tried to sell the aircraft to Naval Aviation for use as escorts for torpedo bombers. Additional fuel tanks were fitted in the wings and fuselage of 3810102 to carry an additional 218 litres (48 imp gal; 58 US gal) of fuel and the capacity of the oil tank was increased to 78 litres (17 imp gal; 21 US gal). These changes increased its empty weight to 3,028 kg (6,680 lb) and its take-off weight to 3,931 kg (8,650 lb; 1,038 US gal). A new round of State trials began on 9 October 1947, but these were delayed by bad weather and reliability issues. Only six flights totaling two hours and twenty-five minutes had been completed by 21 January 1948 and the VRDK had only been run for a minute and half during a ground test. The I-250 was unsurprisingly declared to have failed the trials on 3 April 1948.

Specifications (first prototype)



General characteristics

- **Crew:** 1
- **Length:** 8.19 m (26 ft 10 in)
- **Wingspan:** 9.5 m (31 ft 2 in)
- **Height:** 3.7 m (12 ft 2 in)
- **Wing area:** 15 m² (160 sq ft)
- **Empty weight:** 2,797 kg (6,166 lb)
- **Gross weight:** 3,680 kg (8,113 lb)
- **Fuel capacity:** 612 litres (135 imp gal; 162 US gal)

- **Powerplant:** 1 × Klimov VK-107R liquid-cooled V12 engine, 1,230 kW (1,650 hp)
- **Powerplant:** 1 × VRDK motorjet, 6 kN (1,300 lbf) thrust
- **Propellers:** 3-bladed AV-10P-60, 3.1 m (10 ft 2 in) diameter

Performance

- **Maximum speed:** 820 km/h (510 mph; 440 kn)
- **Range:** 790 km (491 mi; 427 nmi)
- **Service ceiling:** 11,900 m (39,042 ft)
- **Time to altitude:** 5,000 m (16,400 ft) in 3.9 min (with VRDK)
- **Wing loading:** 245 kg/m² (50 lb/sq ft)

Armament

- **Guns:** 3 × 20 mm Berezin B-20 cannons (160 rounds each)

Chapter 8

Lockheed NF-104A

NF-104A



Lockheed NF-104A, 56-0756, climbing with rocket power

Role	Aerospace trainer
Manufacturer	Lockheed Aircraft Corporation
Designed by	Clarence "Kelly" Johnson
First flight	9 July 1963
Introduction	1 October 1963
Retired	June 1971
Primary user	United States Air Force
Number built	3

Unit cost	\$5,363,322 (modification cost for all three aircraft)
Developed from	F-104A Starfighter

The **Lockheed NF-104A** was an American mixed power, high-performance, supersonic aerospace trainer that served as a low cost astronaut training vehicle for the X-15 and projected X-20 Dyna-Soar programs.

Three aircraft were modified from existing Lockheed F-104A airframes and served with the Aerospace Research Pilots School between 1963 and 1971, the modifications included a small supplementary rocket engine and a reaction control system for flight in the upper atmosphere. During the test program the maximum altitude reached was over 120,000 ft (36,600 m). One of the aircraft was destroyed in an accident while being flown by Chuck Yeager. The accident was depicted in the book *The Right Stuff* and the film of the same name.

Development

With the advent of manned spaceflight in the early 1960s, the United States Air Force Experimental Flight Test Pilot's School at Edwards Air Force Base was renamed the Aerospace Research Pilots School (ARPS), with the emphasis on training moving away from the traditional test pilot course to a more spaceflight oriented curriculum.

Initial use of unmodified F-104 aircraft

A number of standard production F-104 Starfighter aircraft were obtained (including F-104D two-seat versions) and used by the ARPS to simulate the low lift/high drag glide approach path profiles of the X-15 and the projected X-20 Dyna-Soar program. These maneuvers were commenced at 12,000 ft (3,700 m) where the F-104 engine was throttled back to 80% power; and with the flaps, speedbrakes and landing gear extended, the aircraft was established in a 30° dive with a pull-out for the landing flare starting at 1,500 ft (460 m) above the ground. These glide approaches gave little room for error. A modified Gulfstream G-II has been used by NASA for similar training for the Space Shuttle program.

Reaction Control System



JF-104 during RCS testing

It was realized that normal aircraft control surfaces had little or no effect in the thin atmosphere of the stratosphere and that any aircraft operating at extremely high altitudes would need to be equipped with a reaction control system (RCS). A modified version of the Bell X-1 was used for initial RCS tests, but was grounded after technical problems and was replaced with a NASA-modified Lockheed F-104A (55-2961) in 1959 which carried RCS systems on its wing tips and in the fuselage nose. This aircraft (designated JF-104) achieved a maximum altitude of 83,000 ft (25,000 m) during the test program. Pilots who flew this aircraft included Neil Armstrong who gained valuable experience in using the RCS system. Pilots complained that the instrument displays were difficult to read and were not accurate enough for the critical zoom climb profiles required to reach high altitudes.

Lockheed contract

Lockheed was awarded a contract by the USAF to modify three F-104A aircraft for the dedicated role of aerospace trainer (AST) in 1962. The airframes were taken out of storage at AMARC and transported to the company factory for modification.

Design and flight profile

The F-104A design was already established as a lightweight, high performance aircraft; but for the AST project, emphasis was placed on removing unnecessary equipment, fitting a rocket engine to supplement the existing jet engine, fitting an onboard RCS system and improving the instrumentation required. The following details give the main differences between the production version and the AST:

Wing

The wingspan of the NF-104A was increased by adding tip extensions to the existing planform. This modification was needed to house the RCS roll control thrusters and would also decrease the type's wing loading.

Tail surfaces

The vertical fin and rudder were replaced by the larger area versions from the two-seat F-104 and were structurally modified to allow installation of the rocket engine.

Fuselage

The fiberglass nose radome was replaced with an aluminum skin and housed the pitch and yaw RCS thrusters. The air intakes originally designed by Ben Rich were of the same fixed geometry as the F-104A but included extensions to the inlet shock cones for optimum jet engine operation at higher Mach numbers. Internal fuselage differences included provision for rocket fuel oxidizer tanks, deletion of the M61 Vulcan cannon, Radar equipment and unnecessary avionics. A nitrogen tank was installed for cabin pressurization purposes, this was required as there would be no bleed air available from the engine after its normal and expected cutoff in the climb phase. Contrary to popular misconception, the jet engine was not allowed to flameout but had to be gradually throttled down and then cutoff as EGT temperatures ramped up towards the danger point for the turbojet's integrity.

Rocket engine

In addition to the standard J79 jet engine a Rocketdyne AR2-3 rocket engine was fitted at the base of the vertical fin. This engine burned a mixture of JP-4 jet fuel and 90% hydrogen peroxide oxidizer solution. The NF-104 carried enough oxidizer for approximately 100 seconds of rocket engine operation. The thrust level could be adjusted to maximum or approximately half power by the pilot using an additional throttle lever on the left side of the cockpit.

Reaction Control System

The Reaction Control System or RCS consisted of eight pitch/yaw motors (four for each axis) and four roll motors. They used the same kind of hydrogen peroxide fuel as the

main rocket engine from a dedicated 155 lb (70 kg) fuel tank and were controlled by the pilot using a handle mounted in the instrument panel. The pitch/yaw motors were rated at 113 lbf (500 N) thrust each and the roll motors were rated at 43 lbf (190 N) thrust.

Typical flight profile



Chuck Yeager in the cockpit of an NF-104A, 4 December 1963

The NF-104A was able to reach great altitudes through a combination of zoom climbing (trading speed for altitude) and use of the rocket engine. A typical mission involved a level acceleration at 35,000 ft (11,000 m) to Mach 1.9 where the rocket engine would be ignited, and on reaching Mach 2.1 the aircraft would be pitched up to a climb angle of 50-70° by carefully applying a load equal to 3.5 g. The J79 afterburner would start to be throttled down at approximately 70,000 ft (21,000 m) followed shortly after by manual fuel cutoff of the main jet engine itself around 85,000 ft (26,000 m) to prevent fast rising engine temperatures from damaging the turbojet. After continuing over the top of its ballistic arc the NF-104 would descend back into denser air where the main engine could be restarted using the windmill restart technique for recovery to a landing.

Operational history

First NF-104A

The first NF-104A (USAF 56-0756) was accepted by the USAF on 1 October 1963. It quickly established a new unofficial altitude record of 118,860 ft (36,230 m) and surpassed this on 6 December 1963 by achieving an altitude of 120,800 ft (36,800 m). It suffered an inflight rocket motor explosion in June 1971. Although the pilot was able to land safely, the damaged aircraft was retired and marked the end of the NF-104 project. This aircraft was reported as scrapped.

Second NF-104A



NF-104A Tail Number 760 at the USAF Test Pilot School

The second NF-104A (USAF 56-0760) was accepted by the USAF on 26 October 1963. After retirement, this aircraft was mounted on a pole outside the U.S. Air Force Test Pilot School at Edwards Air Force Base and can still be seen there today. The extended wing tips, RCS metal nose cone and other parts from 56-0760 were loaned to Daryl Greenamyer for his civilian aviation record attempts using a highly modified F-104. When he was forced to eject during a record flight, his aircraft was destroyed and the parts were never returned.

Third NF-104A

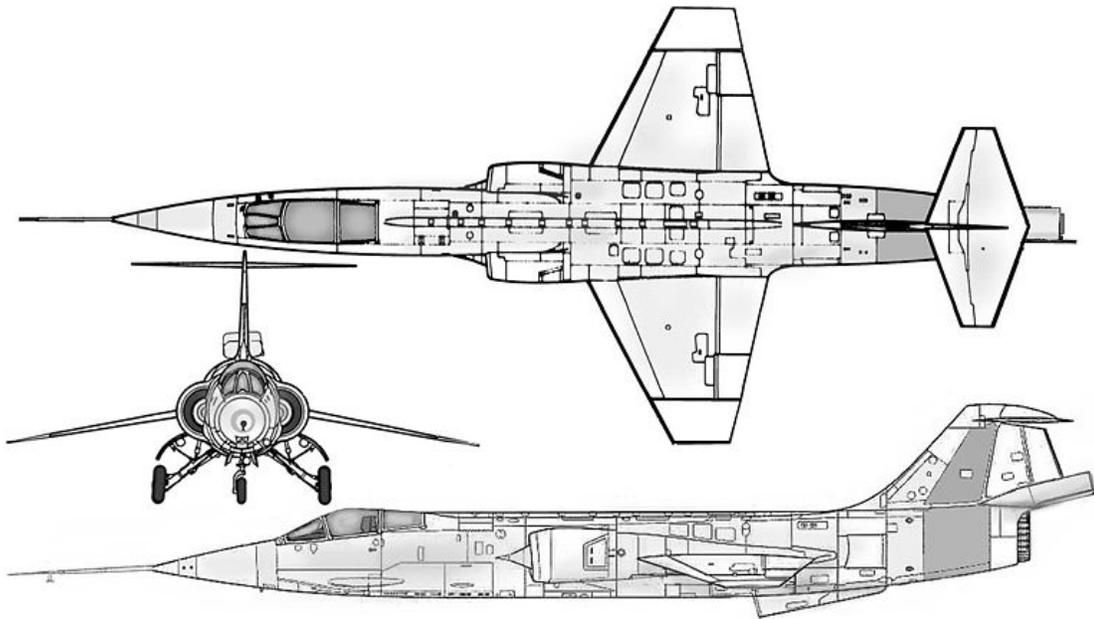
The third NF-104A (USAF 56-0762) was delivered to the USAF on 1 November 1963, and was destroyed in a crash while being piloted by Chuck Yeager on 10 December 1963. This accident was depicted in the book *The Right Stuff* and the film of the same name; although the aircraft used for filming was a standard F-104G flying with its wingtip fuel tanks removed, but otherwise lacking any of the NF-104A's modifications, most visibly the rocket engine pod at the base of the vertical stabilizer.

Operators

 United States

- United States Air Force

Specifications (NF-104A)



General characteristics

- **Crew:** 1
- **Length:** 54 ft 9 in (16.6 m)
- **Wingspan:** 25 ft 9 in (7.84 m)
- **Height:** 13 ft 6 in (4.1 m)
- **Wing area:** 212.8 ft² (19.77 m²)
- **Airfoil:** Bi-convex 3.36%
- **Empty weight:** 13,500 lb (6,080 kg)
- **Loaded weight:** 21,400 lb (9,890 kg)
- **Max takeoff weight:** 21,400 lb (9,890 kg)
- **Powerplant:**

- 1× General Electric J79-GE-3B turbojet, 9,600 lbf (43.54 kN)
- 1× Rocketdyne AR2-3 liquid fuelled rocket engine, 6,000 lbf (27.2 kN)

Performance

- **Maximum speed:** Mach 2.2

Chapter 9

Republic XF-91 Thunderceptor

XF-91 Thunderceptor



Role	Interceptor
Manufacturer	Republic Aviation
First flight	9 May 1949
Status	Cancelled
Number built	2
Unit cost	US\$11.6 million for the program
Developed from	F-84 Thunderjet

The **Republic XF-91 Thunderceptor** was a mixed-propulsion interceptor using a jet engine for most flight, and a cluster of four small rocket engines for added thrust during climb and interception. The design was largely obsolete by the time it was completed due to the rapidly increasing performance of contemporary jet engines, and was built to the extent of two prototypes only. One of these was the first US fighter to exceed Mach 1 in level flight.

Design and development

The Thunderceptor design was one of two swept-wing modifications based on the original F-84 Thunderjet, the other being the F-84F Thunderstreak which was developed later. A serious problem with most swept wing designs of the era was dangerous performance at low speeds and high angle of attack. The stagnant airflow over the wing tended to "slide" towards the wingtips, which caused them to stall before the rest of the wing at high angles of attack. In this situation the center of lift would rapidly shift forward relative to the center of mass, pitching the nose up and leading to an even greater angle of attack or, in extreme cases, end-over-end tumbling of the aircraft. Aircraft caught in this regime would often stall and crash, and a rash of such accidents on the F-100 Super Sabre led to the term Sabre dance. The most famous incident was the loss of F-100C-20-NA Super Sabre 54-1907 during an attempted emergency landing at Edwards AFB, California on 10 January 1956 which was caught by film cameras set up for an unrelated test. The pilot fought to retain control as he rode the knife-edge of the flight envelope but fell off on one wing, hit the ground and exploded with fatal results.

The Thunderceptor's most notable design feature was intended to address this problem. The wings were built to have considerably more chord (distance from front to back) at the tip than root, allowing them to generate more lift. This neatly addressed the problem of Sabre dance by delaying the point of stall on the tip to that of the entire wing. A side effect of this design was that the tips had more internal room, so the landing gear was mounted to retract outward with the wheels lying in the wingtips, using two small tires instead of one larger one. Another design change was the ability to vary the angle of incidence of the wing as a whole, tilting it up for low speed operations during takeoff and landing, and then "leveling it off" for high-speed flight and cruise. This allowed the fuselage to remain closer to level while landing, greatly improving visibility.

In keeping with its intended role as an interceptor, the nose was redesigned to incorporate radar, forcing them to move the air intake for the engine from its original nose-mounted position to a new intake below it. The fuselage was otherwise very similar to the F-84's. The first prototype did not include the radome, although this was fitted to the second prototype.

Testing and evaluation

The first prototype made its first flight on 9 May 1949, breaking the speed of sound in December 1951. It was later modified with a small radome for gunnery ranging (although not the "full" radome from the second prototype). The second prototype included the full radome and chin-mounted intake, but was otherwise similar. This airframe was later modified to use a V-tail for testing. With both the jet and rockets running, the aircraft could reach Mach 1.71, rather respectable for the early 1950s. Both prototypes completed 192 test flights over the course of five years.

As an interceptor the Thunderceptor was soon eclipsed by designs from other companies, but like the Thunderceptor none of these would go into production. The United States Air

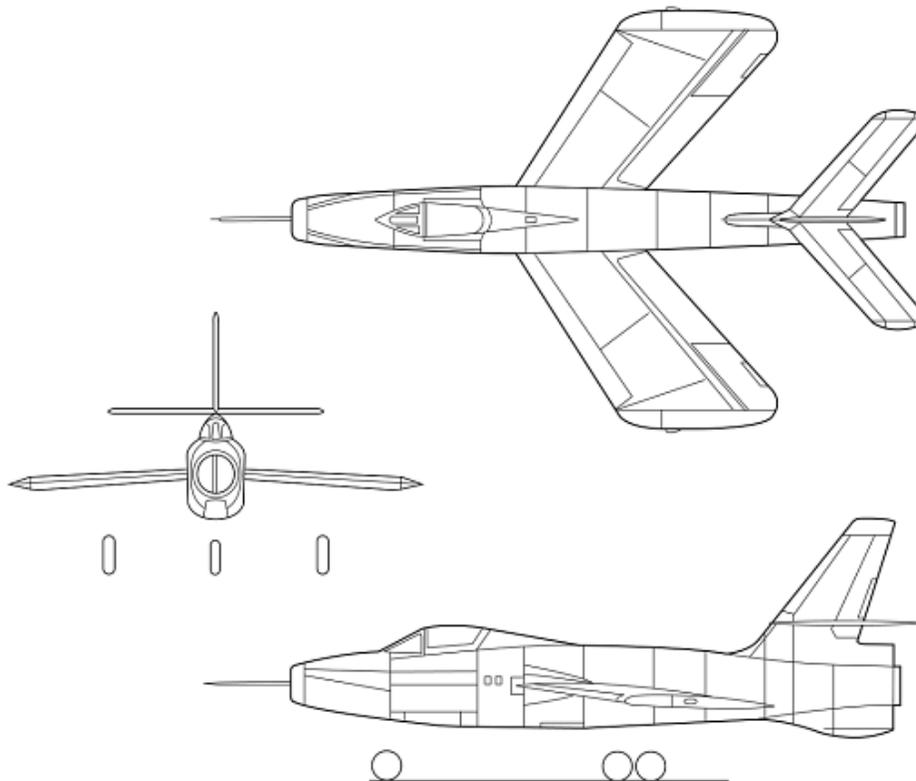
Force decided to wait the short time needed to introduce newer and much more capable designs created as a part of the 1954 interceptor project. The Thunderceptor, like the other interceptor designs of the era, had extremely short flight times on the order of 25 minutes, making them almost useless for protecting an area as large as the United States. The 1954 designs outperformed the XF-91 in speed, range, loiter time, as well as including the radar and fire-control systems needed for night and all-weather operation. The era of the dedicated day fighter-type interceptor was over.

Survivors

The second prototype, *46-681*, had an engine failure during takeoff from Edwards AFB in the summer of 1951. Republic Aviation test pilot Carl Bellinger escaped from the aircraft just as the tail melted off - total flight time was a mere 90 seconds. By the time fire apparatus arrived, driving seven miles across the dry lake bed, the tail section had been reduced to ashes. *46-681* was then fitted with a V or "butterfly" tail (more common on Beechcraft of the era) and was flight tested with this configuration. It was later used at Edwards AFB as a crash-crew training simulator, then scrapped.

The first prototype, serial *46-680*, is preserved at the National Museum of the United States Air Force.

Specifications (XF-91 Thunderceptor)



Dryden Flight Research Center February 1998
XF-91 Thunderceptor 3-view



General characteristics

- **Crew:** 1
- **Length:** 43 ft 3 in (9.52 m)
- **Wingspan:** 31 ft 3 in (13.18 m)
- **Height:** 18 ft 1 in (5.51 m)
- **Wing area:** 320 ft² (29.73 m²)
- **Empty weight:** 14,140 lb (6,410 kg)
- **Loaded weight:** 18,600 lb (8,400 kg)
- **Max takeoff weight:** 28,300 lb (12,840 kg)
- **Powerplant:**
 - 1× General Electric J47-GE-7 (later GE-17) axial-flow turbojet, 5,200 lbs dry, 6,900 lbs with afterburner and water injection (30,6 kN)
 - 4× Reaction Motors XLR11-RM-9 rocket, 1,500 lbf (7 kN) each

Performance

- **Maximum speed:** 984 mph (1,584 km/h)
- **Range:** 1,170 mi (1,880 km)
- **Service ceiling:** 50,000 to 55,000 ft (15,200 to 16,800 m)
- **Rate of climb:** 47,500 ft in 2.5 minutes (14,500 m)
- **Wing loading:** 58.12 lb/ft² (283 kg/m²)
- **Thrust/weight (jet):** 0.60

Armament

- **Guns:** 4 × 20 mm (.79 in) cannon

Chapter 10

Ryan XF2R Dark Shark and Saunders-Roe SR.177

Ryan XF2R Dark Shark

XF2R Dark Shark



Role	Fighter
Manufacturer	Ryan Aeronautical Company
Status	Cancelled
Number built	1 prototype
Developed from	FR Fireball

The **Ryan XF2R Dark Shark** was an experimental aircraft built for the United States Navy that combined turboprop and turbojet propulsion. It was based on Ryan's earlier FR Fireball, but replaced the Fireball's piston engine with a General Electric T-31 turboprop engine driving a huge 4-bladed Hamilton Standard propeller.

The turboprop made for much improved performance over the Fireball, but the Navy showed little interest in it; by that time, they had abandoned the idea of the combination fighter and were instead looking into all-jet fighters.

The United States Air Force, however, showed a little more interest; they were at the time evaluating the Convair XP-81 of similar concept, and asked Ryan to modify the XF2R to use the Westinghouse J-34 turbojet instead of the General Electric J-31 used previously. Modifications to the prototype created the XF2R-2, with the jet intakes moved to the

sides of the forward fuselage with NACA ducts instead of the inlets in the wing leading edge used before.

Although the Dark Shark proved to be a capable aircraft, it never got further than the prototype stage; all-jet aircraft were considered superior.

Specifications



The XF2R-1 in flight

General characteristics

- **Crew:** 1
- **Length:** 36 ft 0 in (10.97 m)
- **Wingspan:** 42 ft 0 in (12.80 m)
- **Height:** 14 ft 0 in (4.27 m)
- **Wing area:** 305 ft² (28.3 m²)
- **Loaded weight:** 11,000 lb (4,990 kg)
- **Powerplant:**
 - 1× General Electric J31 turbojet, 1,600 lbf (7.1 kN)
 - 1× General Electric T31 turboprop, 1,760 hp (1,310 kW)

Performance

- **Maximum speed:** 497 mph (432 kn, 800 km/h) (at sea level)
- **Service ceiling:** 39,100 ft (11,900 m)
- **Rate of climb:** 4,850 ft/min (24.64 m/s)
- **Wing loading:** 36.1 lb/ft² (176 kg/m²)

Armament: 4 x 12.7mm machine guns

Saunders-Roe SR.177

SR.177



SR.177 with Red Top missiles

Role	mixed power interceptor
Manufacturer	Saunders-Roe
Number built	0
Developed from	Saunders-Roe SR.53

The **Saunders-Roe SR.177** was a 1950s project to develop a combined jet- and rocket-powered interceptor aircraft for the Royal Air Force and Royal Navy. The German Navy and Airforce also expressed interest and had planned to buy large numbers, but the SR-177 project was cancelled in 1957 after the German Government pulled out and decided to buy Lockheed F-104's instead. Without the orders, the British Government were not prepared to invest the money needed to complete the project. It transpired many years later, that the cancellation was a direct result of multi-million-dollar bribes to German Ministers amongst others by Lockheed in order to secure orders of their F-104 and to remove the SR-177 as competition. A much larger development was studied under the SR.187 project for Operational Requirement F.155, but this work was also cancelled in 1957, after approximately 90% of the first prototype had been completed.

Design and development

In 1952, Saunders-Roe had won a contract to develop a similar aircraft, the **Saunders-Roe SR.53**. However, as development progressed, the shortcomings of the design became increasingly evident. Most particularly, as with the German rocket-powered interceptors of the Second World War, the range and endurance of such an aircraft were limited by the high rate of fuel consumption by the rocket engine. However, as turbojets developed and became increasingly powerful and efficient, soon new powerplants were available that would make the aircraft more practical.

The SR.177 began as an advanced design concept for the SR.53, but when a development contract was issued by the Ministry of Defence (specification F.155), the project was given its own designation.

The most significant difference between the two aircraft was the use of a jet engine with nearly five times the thrust of the one chosen for the earlier aircraft. This meant that

while the SR.53 relied mostly on its rocket engine for climbing, the SR.177 would be able to add considerable endurance by conserving use of its rocket for the dash towards a target only. It was expected that the added endurance would allow the SR.177 to perform roles other than pure interception, and these were expected to include strike and reconnaissance. The SR.53 design was considerably enlarged to accommodate the new engine, and the original sleek lines were forfeited for a large, chin mounted intake to supply it with air.

Funding was secured in July 1956 for a total of 27 aircraft, and the first was expected to fly by April (later, October) 1958. However, 1957 was to see a massive re-thinking of air defence philosophy in the UK, outlined in the 1957 Defence White Paper which called for piloted warplanes to be replaced by missiles. By the time that the programme was axed later that year, the aircraft had proceeded little past mock-up stage. In 1957 a development contract for the SR.177 was announced for its use with the Royal Navy.

Work on the aircraft continued a little longer, however, in the anticipation of continued interest from Germany. The British Ministry of Supply agreed to continue funding development of five of the six prototypes, but nothing was to come of it. The German government had changed its priorities from looking for an interceptor to a strike fighter, leading Saunders-Roe to redesign the aircraft for this role. This was followed immediately by another redesign when Rolls-Royce successfully convinced the German government to replace the de Havilland engine intended for the SR.177 with a Rolls-Royce turbojet, the RB.153. Even with Heinkel preparing to manufacture the aircraft locally under licence, Germany withdrew support in December 1957. The Minister had visited the German government in November 1957 as the Germans wanted the arrangements to be between governments instead of between their Government and Saunders-Roe.

Cancellation

Of the remaining aircraft under consideration the West German Government chose to purchase the F-104 Starfighter instead to meet the role of "high-altitude reconnaissance machine, a tactical fighter-bomber, and an all-weather fighter", along with most of the European governments. This Lockheed coup, known as the "Deal of the Century", caused major political controversy in Europe and West German Minister of Defence Franz Josef Strauss was almost forced to resign over the issue. During later investigation into Lockheed's business practices it was discovered that Lockheed had paid out millions of dollars in "sales incentives" in each of these countries to secure the deal. Prince Bernhard of the Netherlands confessed to taking more than one million USD in bribes from Lockheed to buy the F-104.

With the withdrawal of German interest and no requirement for the SR.177 by the RAF, the existing Royal Navy requirement was considered not worth proceeding with and the Ministry of Supply cancelled the project. Saunders-Roe announced an expected 1,000 redundancies as a result.

Specifications

General characteristics

- **Crew:** one
- **Length:** 50 ft (15.2 m)
- **Wingspan:** 30 ft (9.1 m)
- **Height:** 14 ft (4.3 m)
- **Loaded weight:** 25,500 lb (11,570 kg)
- **Powerplant:**
 - 1× de Havilland Gyron Junior turbojet, 8,000 lbf (35.6 kN)
 - 1× de Havilland Spectre liquid fuel rocket, 8,000 lbf (35.6 kN)

Performance

- **Maximum speed:** 1,550 mph (2,500 km/h) estimated
- **Service ceiling:** 67,000 ft (20,500 m) estimated
- **Rate of climb:** 60,000 ft/min (18,300 m/s) estimated

Armament

- **Missiles:** 2 Firestreak air-to-air missiles

Avionics

AI-23 airborne interception radar

Chapter 11

Saunders-Roe SR.53

Saunders Roe SR.53



The second SR.53 on display at the September 1957 Farnborough Air Show

Role	Interceptor
Manufacturer	Saunders-Roe
Designed by	Maurice Brennan
First flight	16 May 1957
Status	Experimental
Primary user	United Kingdom
Number built	2
Variants	Saunders-Roe SR.177

The **Saunders-Roe SR.53** was a prototype interceptor aircraft of mixed jet and rocket propulsion developed for the Royal Air Force in the early 1950s. Although its performance was promising, the need for such an aircraft was soon overtaken by surface-to-air missile development, consequently the project was cancelled after 56 test flights.

Design and development

The Second World War demonstrated the importance of strategic bombing to modern warfare, and as the Cold War developed, devising effective air defence against large waves of enemy bomber aircraft became a priority for many nations. Nazi Germany had

looked to rocket-powered aircraft to fill this niche, with machines like the Messerschmitt Me 163 and Bachem Ba 349, which were capable of unparalleled rates-of-climb, enabling them to (at least in theory) rise to meet and intercept enemy bombers before they reached their targets. German rocket technology was studied extensively by the Allies in the aftermath of the war, and in light of the threat of the growing Soviet strategic bomber fleet and that nation's newly-developed atomic weapons, the UK's Air Ministry drafted an Operational Requirement O.R. 301 in May 1951 for a rocket-powered interceptor that could reach an altitude of 60,000 ft (18,300 m) in just 2 minutes 30 seconds. This was circulated to the nation's aircraft manufacturers the following February.

The development of the de Havilland Sprite (5,000 lb thrust) and the Armstrong Siddeley Snarler (2,000 lb thrust) for RATO use led to the possibility of a more powerful rocket engine being developed as the planned powerplant for a "point defence" interceptor. The requirements of the O.R. 301 were considered onerous including a ramp launch and landing on a skid, and with the compliance of the companies approached to tender, the amended Specification G124T allowed for a mixed powerplant configuration and a conventional undercarriage.



Colour drawing of the first SR.53

Of the six companies that tendered proposals, two were selected for development contracts, A.V. Roe with their Avro 720 and Saunders-Roe with their **SR.53**. Further refinement of the concept led to the defined Specification O.R. 337. The SR.53 itself was a sleek aircraft with a sharply pointed nose, delta-like wing, and a T-tail. The Armstrong Siddeley Viper jet and de Havilland Spectre rocket engine and exhausts were mounted one atop the other in the tail.

By September 1953, the programme to develop these aircraft came under scrutiny due to cost cuts, and the Avro 720 was abandoned, although it seemed almost ready to fly at this point. One of the reasons for preferring the SR.53 was although the aircraft was developmentally behind, its use of hydrogen peroxide as an oxidiser was viewed as less problematic than the Avro 720's use of liquid oxygen. With an original contract to build three prototypes, the SR.53 was scheduled for a first flight in July 1954 with a service

introduction date set for 1957. At the same time, Saunders-Roe began work on a derivative design, the SR.177, which was large enough to carry a useful radar, essential to interception at the high altitudes where the new fighter was meant to operate, despite the fact that the specification did not require it. The new, larger aircraft was developed into versions for maritime use by the Royal Navy and for West Germany as well as for the RAF.

Operational history

The complexity of the design caused a series of setbacks, notably an explosion during ground tests of the Spectre rocket engine. The SR.53's first flight began to fall further and further behind schedule. On 16 May 1957, Squadron Leader John S. Booth DFC was at the controls of XD145 for the first test flight, following up with the maiden flight of the second prototype XD151, on 6 December 1957. Test results indicated "...an extremely docile and exceedingly pleasant aircraft to fly, with very well harmonized controls." Both prototypes flew a total of 56 test flights, with Mach 1.33 speeds being obtained.

While testing at RAE Boscombe Down, XD151 crashed on 15 June 1958 during an aborted takeoff on its 12th flight. Running off the runway, the aircraft struck a concrete approach light, exploding on impact and killing its pilot, Squadron Leader Booth. The remaining prototype continued to fly with Lt Cdr Peter Lamb taking over the flight test programme.

Cancellation

It was 1957 before the first SR.53 took to the air, just over a month after the infamous 1957 Defence White Paper had been published outlining the British government's policy to largely abandon piloted aircraft in favour of concentrating on missile development. At the same time, jet engine development had progressed a long way in the six years since the SR.53's initial design. Combined with the fact that improvements in radar had meant that any incoming bomber threat could be detected much earlier, the need for an aircraft like the SR.53 had disappeared, and the project was cancelled on 29 July 1960, with the third prototype (XD153) never built.

Aircraft on display

The first SR.53 prototype, *XD145*, is preserved at the Royal Air Force Museum Cosford near Wolverhampton.

Operators

 United Kingdom

- Ministry of Supply

Specifications

General characteristics

- **Crew:** One, pilot
- **Length:** 45 ft 0 in (13.72 m)
- **Wingspan:** 25 ft 1½ in (7.66 m)
- **Height:** 10 ft 10 in (3.30 m)
- **Wing area:** 274 ft² (25.5 m²)
- **Airfoil:** RAE102
- **Empty weight:** 7,400 lb (3,360 kg)
- **Loaded weight:** 18,400 lb (8,360 kg)
- **Powerplant:**
 - 1× Armstrong Siddeley Viper 8 turbojet, 1,640 lb (7.3 kN)
 - 1× de Havilland Spectre rocket, 8,000 lbf (35.7 kN)

Performance

- **Maximum speed:** Mach 2.2
- **Endurance:** 7 minutes at full power
- **Service ceiling:** 67,000 ft (20,420 m)
- **Rate of climb:** 52,800 ft/min (270 m/s) : 2 min 12 sec from brakes to 50,000 ft
- **Wing loading:** 67.2 lb/ft² (328 kg/m²)
- **Thrust/weight (jet):** 0.52

Armament

- **Missiles:** 2 × de Havilland Firestreak infra-red guided missiles

Chapter 12

Hydrogen-Powered Aircraft

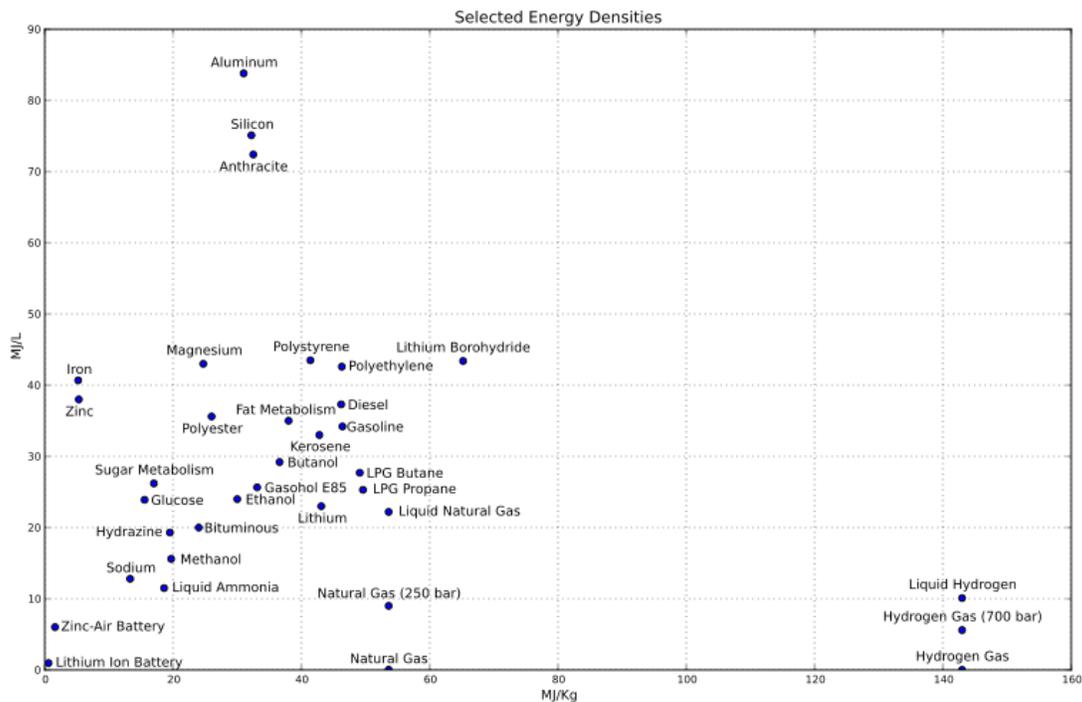


In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

A **hydrogen-powered aircraft** is an airplane that uses hydrogen as a power source.

In aircraft hydrogen can either be burned in some kind of jet engine, or other kind of internal combustion engine, or can be used to power a fuel cell to generate electricity to power a propeller.

Properties of hydrogen



Energy density of fuels - horizontal per mass, vertical per volume

Being an alternative to jet fuel, hydrogen has a higher energy density per unit *mass* but a lower energy density per unit *volume*, and containing the hydrogen at high pressure would require a heavy container. In aircraft heavy containers are not an option, and therefore regular carbon fibre tanks are often used, which can only sustain a pressure of 350 bar. When compared to steel hydrogen containers (used in cars and ships), this is 500 to 700 bar. This decreases the amount of energy that can be spent on the propulsion by half. Alternatively, as with some rockets, cryogenic liquid hydrogen could be employed.

If hydrogen were available in quantity from renewable energy sources, its use in aircraft would produce fewer greenhouse gases (water vapor and a small amount of nitrogen) than current aircraft. Currently, very little hydrogen is produced using renewable energy sources, and there are several serious obstacles to the use of hydrogen in aircraft and other vehicles. According to research at the Pennsylvania State University in 2006, large commercial hydrogen aircraft could be built by 2020 but "will probably not enter service until closer to 2040."

The European Union's research project in cooperation with Airbus and 34 other partner companies dubbed CRYOPLANE assessed the technical feasibility, safety, environmental compatibility and economic viability of using liquid hydrogen as an aviation fuel. This was concluded in 2002 (with the final report published in 2003).

Liquid hydrogen is one of the best coolants used in engineering, and it has been proposed to use this property for cooling intake air for very high speed aircraft, or even for cooling the vehicle's skin itself particularly for scramjet-powered aircraft.

Properties of hydrogen aircraft

Hydrogen aircraft are usually designed with the liquid hydrogen fuel carried inside the fuselage, in order to minimize surface-area and reduce boil-off. Normal aircraft use wings for storing fuel.

Liquid hydrogen has about four times the volume for the same amount of energy of kerosene based jet-fuel. In addition, its highly volatile nature precludes storing the fuel in the wings, as with conventional transport aircraft. Therefore, most liquid hydrogen aircraft designs store the fuel in the fuselage, leading to a larger fuselage length and diameter than a conventional kerosene fueled aircraft. If that were the end of the story, the hydrogen-fueled aircraft would have lower performance than the kerosene aircraft due to the extra wetted area of the fuselage. The larger fuselage size causes more skin friction drag and wave drag. Hydrogen is about one-third of the weight of kerosene jet-fuel for the same amount of energy. This means that for the same range and performance (ignoring the effect of volume), the hydrogen aircraft would have about one-third of the fuel weight. For a Boeing 747-400 type aircraft, this would reduce the Takeoff Gross Weight from 800,000 lbs to approximately 600,000 lbs. Thus, the performance of a hydrogen-fueled aircraft is a trade-off of the larger wetted area and lower fuel weight. This trade-off depends on the size of the aircraft.

Liquid hydrogen was proposed for use on the scramjet-based National Aerospace Plane.

Hydrogen aircraft demonstrations

Several demonstrations of hydrogen-powered aircraft have been performed using purpose-build airplanes.

Boeing Research & Technology Europe (BR&TE) made a civilian aircraft from a 2-seat Dimona motor glider running on a fuel cell (called Theator Airplane)". Lange Aviation GmbH also made a hydrogen-powered airplane with its Antares DLR-H2 airplane.

These aircraft are of course configured in such fashion that the current low energy output from hydrogen propulsion (a result of the low-pressure hydrogen tanks) do not pose a problem. For example the Boeing Theator airplane only required 45 kW to take off, and 20 kW to stay airborne.

In July 2010 Boeing also unveiled its hydrogen powered Phantom Eye UAV, that uses two Ford Motor Company internal combustion engines converted to operate on hydrogen.

Current aircraft

- The Russian manufacturer Tupolev built a prototype hydrogen-powered version of the Tu-154 airliner, named the Tu-155, which made its first flight in 1989.
- Northrop Grumman has successfully tested their X-47B Unmanned Combat Air System (UCAS) for Carrier Operations during 2010. This unmanned aircraft, or drone, which is still a prototype, can be programmed to perform a particular mission totally autonomously and/or remotely controlled by a pilot. It can operate at altitudes up to 16,000 ft. The liquid hydrogen version that has been successfully tested on 2010 can fly for 5 to 7 days without refuelling.

Proposed hydrogen aircraft

- Reaction Engines Skylon orbital hydrogen fuelled jet plane
- Reaction Engines A2 antipodal hypersonic jet airliner
- DLR Smartfish
- Boeing plans to build a hydrogen-powered jet

Chapter 13

Avatar (Spacecraft)

AVATAR RLV



A scaled down version of AVATAR undergoing aero-elastic test.

Function	Unmanned reusable spaceplane technology demonstrator
Manufacturer	DRDO/ISRO
Country of origin	 India
Size	
Diameter	N/A
Stages	1/2
Capacity	
Launch history	
Status	Under Development
Launch sites	Satish Dhawan Space Centre
Total launches	0
Maiden flight	2011, projected

AVATAR (Sanskrit: अवतार) (from "Aerobic Vehicle for Hypersonic Aerospace Transportation") is a single-stage reusable rocketplane capable of horizontal takeoff and landing, being developed by India's Defense Research and Development Organization along with Indian Space Research Organization and other research institutions; it could be used for cheaper military and civilian satellite launches.

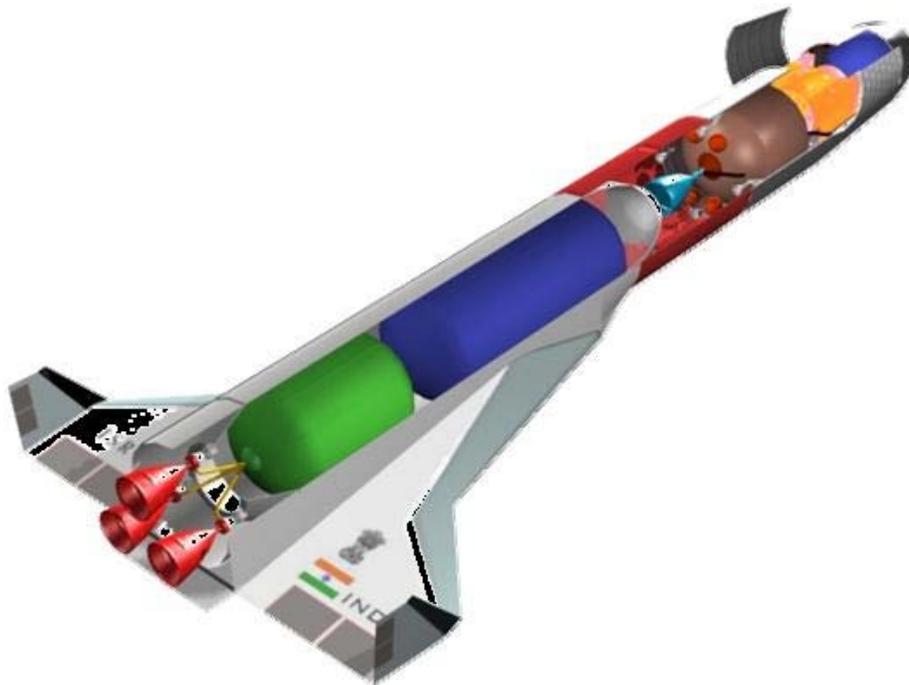
When operational, it is planned to be capable of delivering a payload weighing up to 1,000 kg to low earth orbit. It would be the cheapest way to deliver material to space at about US\$67/kg. Each craft is expected to withstand 100 launches.

Concept

The idea is to develop a hyperplane vehicle that can take off from conventional airfields, collect air in the atmosphere on the way up, liquefy it, separate oxygen and store it on board for subsequent flight beyond the atmosphere. The AVATAR RLV was first announced in May 1998 at the Aero India 98 exhibition held at Bangalore. It is planned to be the size of a MiG-25 fighter and would be capable of delivering a 500 kg to 1,000 kg payload to low earth orbit at very low cost for an estimated vehicle life of 100 launches.

AVATAR is proposed to weigh only 25 tonnes in which 60 per cent of mass will be liquid hydrogen fuel. The oxygen required by the vehicle for combustion is collected from the atmosphere, thus reducing the need to carry oxygen during launch. AVATAR is said to be capable of entering into a 100-km orbit in a single stage and launching satellites weighing up to one tonne.

Operation



AVATAR RLV-TSTO

AVATAR would take off horizontally like a conventional airplane from a conventional airstrip using turbo-ramjet engines that burn air and hydrogen. Once at a cruising altitude, the vehicle would use scramjet propulsion to accelerate from Mach 4 to Mach 8. During

this cruising phase, an on-board system would collect air from the atmosphere, from which liquid oxygen would be separated and stored. The liquid oxygen collected then would be used in the final flight phase when the rocket engine burns the collected liquid oxygen and the carried hydrogen to attain orbit. The vehicle would be designed to permit at least a hundred re-entries into the atmosphere.

Dr. M R Suresh, a senior ISRO official, stated that, "The dream of making a vehicle which can take off from a runway like an aircraft, and to return to the runway after deploying the spacecraft in the desired orbit (or Single-stage-to-orbit or SSTO) can be fulfilled only by the availability of more advanced high strength but low density materials so that the structural mass of the vehicle could be reduced considerably from the present levels. The advent of nano-technology could play a deciding factor in developing such exotic materials. However, the material technology available today can realize a Two Stage To Orbit (TSTO) vehicle only and the configuration of the vehicle which is being considered. However, the before realizing the RLV-TSTO it is important to perfect many critical technologies pertaining to hypersonic reentry vehicles. Hence a technology demonstrator vehicle (RLV-TD) is being developed."

Development



A model of the RLV-TD

AVATAR is being developed by India's Defense Research and Development Organization. Air Commodore Raghavan Gopaldaswami, former chief of Bharat Dynamics Ltd, Hyderabad, is heading the project. He coined the name and made the presentation on the space plane at the global conference on propulsion at Salt Lake City (USA) on July 10, 2001. Gopaldaswami said the idea for AVATAR originated from the work published by the RAND Corporation of the United States in 1987.

AVATAR is currently in the prototype testing stage and an initial development budget of only \$5 million is allocated. Along with DRDO team development of critical technology components were undertaken by as many as 23 academic institutions (Indian Institutes of Technology, Indian Institute of Science et al.) along with ISRO in India. Both the scramjet engine concept and the liquid oxygen collection process have already undergone successful tests at DRDO and at the IISC. DRDO has approved further testing of the liquid oxygen process and assigned a team to conduct a detailed review of the vehicle's design.

Currently DRDO plans to build and fly a scaled-down version of AVATAR, weighing just 3 tonnes at takeoff. The project is headed by Vikram Sarabhai Space Centre in Thiruvananthapuram. The mini AVATAR is to be built by a Hyderabad-based private company called CIM Technologies, project completion data is still not finalized. The prototype will be launched using the PSLV and will demonstrate all technologies used in AVATAR including oxygen collection. The aerodynamics characterization of the RLV-TD was done by National Aerospace Laboratories. The AVATAR design has already been patented in India and applications for registration of the design have been filed in patent offices in the United States, Germany, Russia and China.

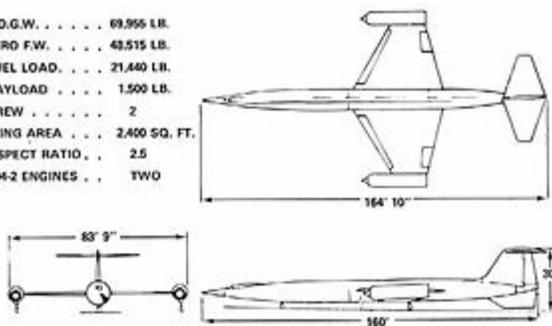
Chapter 14

Lockheed CL-400 Suntan and Reaction Engines A2

Lockheed CL-400 Suntan

CL-400

T.O.G.W. 69,956 LB.
ZERO F.W. 48,515 LB.
FUEL LOAD. 21,440 LB.
PAYLOAD 1,500 LB.
CREW 2
WING AREA 2,400 SQ. FT.
ASPECT RATIO 2.5
304-2 ENGINES TWD



3-view of the Suntan concept aircraft

Role	Proposed reconnaissance aircraft
Manufacturer	Lockheed Aircraft Corporation
Designed by	Clarence L "Kelly" Johnson

Suntan was the code-name of a prototype reconnaissance aircraft program, with the goal of creating a much faster and higher-altitude successor to the U-2, enabled by the use of liquid hydrogen (LH2) as fuel. From 1956-1958, the United States Air Force funded a highly secretive program of research and development on the aircraft (the CL-400, designed at the Lockheed Skunk Works) and engine design, and made significant investments in large-scale LH2 production. In addition to Lockheed, Pratt and Whitney (part of United Aircraft, now United Technologies Corporation) played a major part. Program successes included the concept design of a Mach 2.5 aircraft capable of flying at 30,000 meters, and successful conversion of an existing turbojet engine to run on liquid hydrogen, as well as 25+ hours of testing on a customized LH2 engine design.

Ultimately, budgetary pressures and difficulty achieving sufficient range, plus the fact that an LH2 powered aircraft was considered too dangerous and expensive to maintain led to the project's cancellation. In addition, the unusual fuel would have meant that existing airbases would have needed extensive facilities to handle the aircraft.

However, the aircraft research was redirected to more conventionally-fueled designs and resulted in the successful SR-71.

By advancing the state of the art in LH2 propulsion, and by establishing an industrial infrastructure for high-volume hydrogen production, the groundwork was laid for successful use of liquid hydrogen as a rocket fuel for the Apollo program and the Space Shuttle.

Reaction Engines A2

A2



Artist's concept of the Reaction Engines A2

Role	Hypersonic Airliner
Manufacturer	Unknown
Designed by	Reaction Engines Limited
Status	Under design study

The **Reaction Engines Limited A2** (called the **A2**) is a design study for a hypersonic airliner. The airliner is intended to provide environmentally-friendly, long range and high capacity commercial transportation. It is being examined as part of the LAPCAT programme of the European Union. The plane has not been commercially launched yet, but Reaction Engines Limited, the British design firm, says it could probably be developed into a working aircraft within 25 years, if there is market demand for it.

Development

“ Our work shows that it is possible technically; now it's up to the world to decide if it wants it. ”

— Alan Bond, managing director
of Reaction Engines Limited

The vehicle is intended to have about 20,000 kilometres (12,000 mi) range and good subsonic and supersonic fuel efficiency, thus avoiding the problems inherent in earlier supersonic aircraft. The top speed is projected to be Mach 5+. It calls for the use of liquid hydrogen as a fuel, which has twice the specific impulse of kerosene, and can be used to cool the vehicle and the air entering the engines via a precooler.

The developers say it would be able to fly from Brussels to Sydney in about 4.6 hours, compared to around a complete day of travel with normal aircraft. The cost of a ticket is intended to be roughly business class level.

Design

Capabilities



The LAPCAT A2 concept in the upper atmosphere

Alan Bond told *The Guardian* newspaper:

“ The A2 is designed to leave Brussels International Airport, fly quietly and subsonically out into the north Atlantic at Mach 0.9 before reaching Mach 5 across the North Pole and heading over the Pacific to Australia. ”

The great circle route is not used in this example because the route travels mostly over land. The sonic boom generated by travelling at supersonic speed can cause great discomfort for people on the ground, which was why Concorde was prohibited for flying supersonically over land.

Another advantage of the design is that, while the 143 metre-long A2 is much longer than conventional jets, it would be lighter than a Boeing 747 and could take off and land on current airport runways.

However, the A2 design does not have windows. The heat generated by traveling so quickly makes it difficult to install windows that are not too heavy. One solution Reaction Engines has proposed is to install flat panel displays, showing images of the scene outside.

Engines

The Scimitar engines use related technology to the company's earlier SABRE engine, which is intended for space launch, but here adapted for very long distance, very high speed travel.

Normally, as air enters a jet engine, it is compressed by the inlet, and thus heats up. This means that high speed engines need to be made of technologies and materials that can survive extremely high temperatures. In practice, this inevitably makes the engines heavier and also reduces the amount of fuel that can be burnt to avoid melting the gas turbine section of the engine, which in turn reduces thrust at high speed.

The key design feature for the Scimitar engines is the precooler, which is a heat exchanger that transfers the heat from the incoming air into the hydrogen fuel. This greatly cools the air, which allows the engines to burn more fuel even at very high speed, and allows the engines to be made of lighter, but more heat susceptible, materials such as light alloys. The engine inlet diffuser also has to slow the incoming air to subsonic speeds as if the air moved through the precooler and compressor at supersonic speeds, it would cause damage to them.

The rest of the engine is described as having high-bypass (4:1) turbofan engine features to give it good efficiency and subsonic (quiet) exhaust velocity at low speeds. Unlike SABRE the A2's Scimitar engine would not have rocket engine features.

Specifications

- **Range:** 20,000 kilometres (12,000 mi)
- **Length:** 143 metres (469 ft)
- **Fuel:** Liquid hydrogen
- **Passengers:** 300 (Single Class)
- **Cruising speed:** Mach 5
- **Specific fuel consumption:** 0.86 lbf/lb·h at Mach 5 (40,900 m/s - 4,170 seconds), 0.375 lbf/lb·h at Mach 0.9 (96,000 m/s - 9,600 seconds)
- **Lift to drag ratio:** 11.0 at 5.9 km, Mach 0.9, 5.9 at 25 km Mach 5
- **Noise:** 101 dBa at 450m lateral

Chapter 15

Reaction Engines Skylon

Skylon



The Skylon vehicle is an aircraft designed to reach orbit.

Role	Re-usable Spaceplane
National origin	UK/multinational
Designed by	Reaction Engines Limited
Status	Research and development
Program cost	Projected to be £7.1 billion (~\$12 billion est. 2004)
Unit cost	£190 million (projected)
Developed from	Horizontal Take-Off and Landing (HOTOL) project

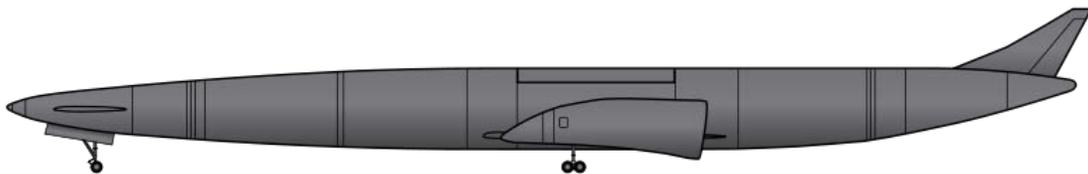
Skylon is a design for an unpowered spaceplane by the British company, Reaction Engines Limited (REL). It uses a combined-cycle, air-breathing jet engine to reach orbit in a single stage. A fleet of vehicles is envisaged; the design is aiming for re-usability up to 200 times. In paper studies, the costs per kilogram of payload are hoped to be lowered from the current £15,000/kg to £650/kg (as of 2011), including the costs of research and development (R&D), with costs expected to fall much more over time after the initial expenditures have amortised. The cost of the program has been estimated by the developer to be about \$12 billion.

The vehicle design is for a hydrogen-powered aircraft that would take off from a conventional runway, and accelerate to Mach 5.4 at 26 km using atmospheric air before

switching the engines to use the internal liquid oxygen (LOX) supply to take it to orbit. It would then release its payload, which can weigh up to 12-tonnes, and re-enter the atmosphere. The payload would be carried in a standardised payload container or passenger compartment.

During re-entry the relatively light vehicle would fly back through the atmosphere and land back at the runway, with its skin protected by a ceramic composite. It would then undergo inspection and any necessary maintenance and, if the design goal is achieved, be able to fly again within two days. As of 2010, only a small portion of the funding required to develop and build Skylon has been secured. The research and development work on the SABRE engine design is proceeding under a small European Space Agency (ESA) grant. In January 2011, REL submitted a proposal to the British Government to request additional funding for the Skylon project.

Technology and innovations



The Skylon spaceplane is designed as a two-engine, "tailless" aircraft, which is fitted with a steerable canard.

Structure of the fuselage

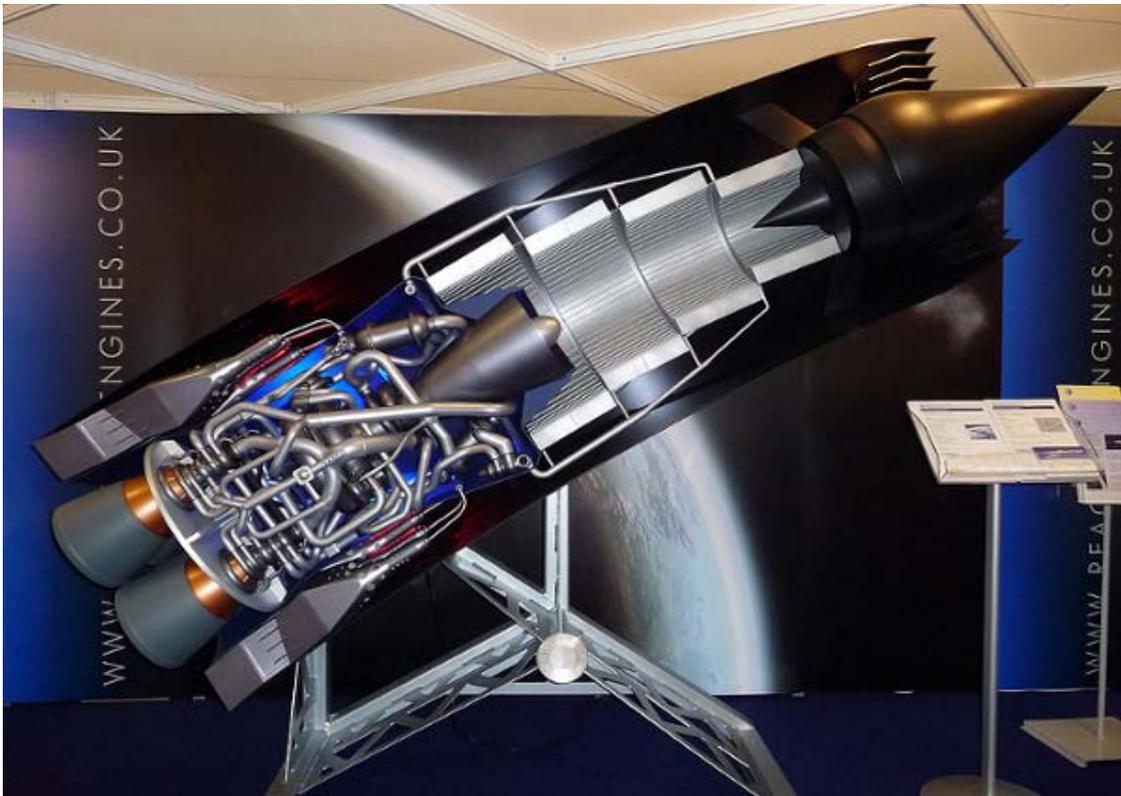
The fuselage of Skylon is expected to be carbon fibre space frame; a light and strong structure that supports the weight of the aluminium fuel tanks and to which the ceramic skin is attached. Multiple layers of reflective foil thermal insulation fill the spaces of the frame.

The currently proposed Skylon model C2 will be a physically large vehicle, with a length of 82 metres (269 ft) and a diameter of 6.3 metres (21 ft). Because it will use a low-density liquid hydrogen fuel, a great volume is needed to contain enough energy to reach orbit. The propellant is intended to be kept at low pressure to minimise stress; a vehicle that is both large and light has an advantage during atmospheric reentry compared to other vehicles due to a low ballistic coefficient. Because of the low ballistic coefficient, Skylon would be slowed at higher altitudes where the air is thinner. As a result, the skin of the vehicle would only reach 1100 Kelvin (K). In contrast, the smaller Space Shuttle is heated to 2000 K on its leading edge, and so employs an extremely heat-resistant but extremely fragile silica thermal protection system. The Skylon design need not use such a system, instead opting for using a far thinner yet durable reinforced ceramic skin. However, due to turbulent flow around the wings during re-entry, some parts of Skylon would need to be actively cooled.

Skylon would employ a highly-loaded tightly spaced wheel assembly, to save weight and also interior space when the wheels are retracted into the fuselage. Because this wheel design distributes the weight of the aircraft and the force of its landing over a smaller area of the runway, it would require a specially strengthened runway. It will possess a retractable undercarriage with high pressure tires and water cooled brakes. If problems were to occur just before a take-off the brakes would be applied to stop the vehicle, the water boiling away to dissipate the heat. Upon a successful take-off, the water would be jettisoned, thus reducing the weight of the undercarriage by many tons. During landing, the empty vehicle would be far lighter, and hence the water would be unneeded. The payload fraction would be significantly greater than normal rockets and the vehicle should be fully reusable (200 times or more).

SABRE Engines

One of the significant features of the Skylon design is the engine, called SABRE. The engines are designed to operate much like a conventional jet engine at up to around Mach 5.5 (1700 m/s), 26 kilometres (16 mi) altitude, beyond which the air inlet closes and the engine operates as a highly efficient rocket to orbital speed.



The Reaction Engines Limited Synergistic Air-Breathing Rocket Engine (SABRE) engine is a key component of the Skylon spaceplane.

The proposed engine for the vehicle is not a scramjet, but a jet engine running combined cycles of a precooled jet engine, rocket engine and ramjet. Originally the key technology

for this type of precooled jet engine did not exist as it required a heat exchanger that was ten times lighter than the state of the art. Research conducted since then has achieved the necessary performance.

Operating an air-breathing jet engine at up to Mach 5.5 is difficult. Several previous engines proposed by other designers have been good as jet engines but performed poorly as rockets. This engine design aims to be a good jet engine within the atmosphere, as well as being an excellent rocket engine outside. The problem with operating at Mach 5.5 has been that the air coming into the engine heats up as it is compressed into the engine, which can cause the engine to overheat. Attempts to avoid these issues typically make the engine much heavier (scramjets/ramjets) or greatly reduce the thrust (conventional turbojets/ramjets). In either case the end result is an engine that has a poor thrust to weight ratio at high speeds, resulting in an engine that is too heavy to assist much in reaching orbit.

The SABRE engine design aims to avoid this by using some of the liquid hydrogen fuel to cool the air at the inlet. The air is then used for combustion much like in a conventional jet. Because the air is cooled at all speeds, the jet can be built of light alloys and the weight is roughly halved. Additionally, more fuel can be burnt at high speed. Beyond Mach 5.5, the air would still be unusably hot despite the cooling, so the air inlet closes and the engine relies solely on on-board liquid oxygen and hydrogen fuel as in a normal rocket.

Because the engine uses the atmosphere as reaction mass at low altitude, it will have a high specific impulse (around 2,800 seconds), and burn about one fifth of the propellant that would have been required by a conventional rocket. Therefore, it would be able to take off with much less total propellant than conventional systems. This, in turn, means that it doesn't need as much lift or thrust, which permits smaller engines, and allows conventional wings to be used. While in the atmosphere, using wings to counteract gravity drag is more fuel-efficient than simply expelling propellant (as in a rocket), again reducing the total amount of propellant needed.

"Single Stage to Orbit" capability

A vehicle that can fly to orbit without staging is known as single stage to orbit (SSTO). Proponents of SSTO claim that staging causes a number of problems such as being difficult, expensive or even impossible to recover, reuse and reassemble the parts and therefore believe that SSTO designs hold the promise of reducing the cost of space-flight.

The Skylon design aims to take off from its specially strengthened runway, fly into low earth orbit, re-enter the atmosphere, and land back on its runway like a conventional aeroplane, without staging, while being fully reusable.

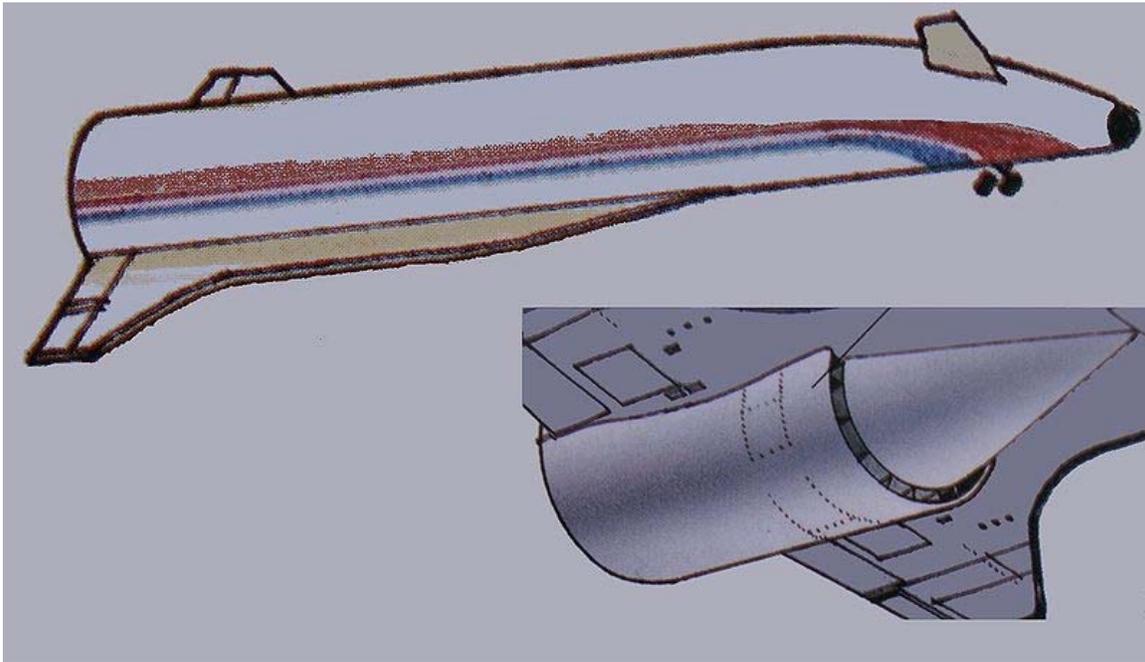
Payload bay

The payload bay of the Skylon C2 design is a cylinder 12.3 metres (40.4 ft) long and 4.6 metres (15 ft) in diameter. It is designed to be comparable with current payload dimensions, and yet able to support the containerization of payloads that Reaction Engines hopes for in the future. To an equatorial orbit, Skylon could deliver 12 tonnes (26,455 lb) to a 300 kilometres (186 mi) height or 10.5 tonnes (23,149 lb) to a 460 kilometres (286 mi) altitude. It could also launch 9.5 tonnes (20,944 lb) to the orbit of the International Space Station, when launching from the equator. Using interchangeable payload containers, Skylon could be fitted to carry satellites or fluid cargo into orbit, or, in a specialised habitation module, up to 30 astronauts in a single launch.

Current project status

As of 2010, the funding required to develop and build the entire craft has not yet been secured, and so current research and development work is focused on the engines, under an ESA grant of €1 million. In January 2011, REL submitted a proposal to the British Government requesting additional funding for the Skylon project.

Research and development programme



The Skylon was developed from the ill-fated British HOTOL project

Skylon is based upon a previous project of Alan Bond, which was known as HOTOL. The development programme of HOTOL began in 1982, a time when space technology was moving towards reusable launch systems such as the American Space Shuttle. In conjunction with British Aerospace and Rolls Royce, a design emerged that proved

highly promising, so much so that the British Government donated £2 million to further their work. However, in 1988, the Conservative government withdrew funding, and the development programme was terminated. Following this major setback, Alan Bond decided to set up his own company, Reaction Engines Limited, with the hope of continuing development with private funding.

After having secured funding, the design of the craft was revisited, undergoing a rigorous redesign throughout much of the 1990s. In the last decade, Reaction Engines has been working with the University of Bristol to develop the engines vital to the success of Skylon. The STRICT/STERN engines produced by this programme were deemed a great success. The next stage of development is to construct a full-sized working prototype of the SABRE Engine.

The differences between Skylon and its predecessor are numerous. For example, HOTOL was to have been launched from a rocket sled (to save weight), whereas Skylon uses a conventional retractable undercarriage. Skylon also uses a different engine design; the SABRE engine is expected to offer higher performance. Another issue that the Skylon design aims to circumvent was the intrinsically poor stability of HOTOL. The weight of the rear-mounted engine tended to make the HOTOL vehicle flip over mid-flight due to the centre of mass lying behind the centre of drag. Attempts to fix this problem ended up sacrificing much of the potential payload that the HOTOL vehicle could carry, and contributed to the failure of the project. Skylon would solve this by placing the engines at the end of the wings closer to the centre of the vehicle and thus moving the centre of mass forward, ahead of the centre of drag.

The complete Skylon project has a projected R&D cost of over \$10 billion and will continue for another 7–10 years. In February 2009, the British National Space Centre (now the UK Space Agency) and ESA announced that they were partially funding work with €1 million Euros (\$1.28 million dollars) on Skylon's engine to produce a demonstration engine by 2011.

The Technology Demonstration Programme will last approximately 2.5 years and will benefit from another €1 million from the ESA. This programme will take Reaction Engines Ltd from a Technology Readiness Level (TRL) of 2/3 up to 4/5. The former UK Minister for Science and Innovation in 2009, Lord Drayson, commented on Skylon in a speech: "This is an example of a British company developing world-beating technology with exciting consequences for the future of space."

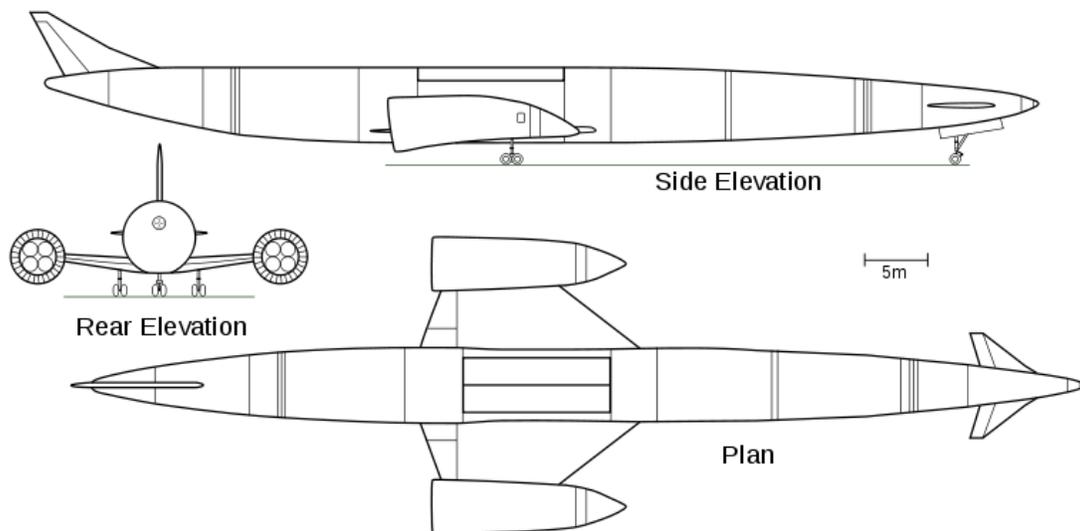
Economics and political will

Once operative, Skylon could potentially lower satellite costs from the current £15,000/kg to £650/kg, according to evidence submitted to the UK parliament by Reaction Engines Ltd. However, funding and support from the British government has not been easy to establish.

Request for funding from the British government was undertaken in 2000, with a proposal that could have offered a large potential return on investment. The request was not taken up at that time. Subsequent discussions with the British National Space Centre led to agreement in 2009 on a co-funding agreement between BNSC, ESA and REL to continue technology development for the SABRE engine. Testing of the SABRE engine will commence in June 2011 with the start of Phase 3 in the Skylon development programme. Pre-orders are expected in the 2011–2013 time frame coinciding with the formation of the manufacturing consortium. According to David Willetts, the UK Minister of State for Universities and Science:

"The European Space Agency is funding proof of concept work for Skylon from UK contributions. This work is focusing on demonstrating the viability of the advanced British engine technology that would underpin the project. Initial work will be completed in mid 2011 and if the trial is successful, we will work with industry to consider next steps."

Specifications



Skylon C2

General characteristics

- **Crew:** automated
- **Capacity:** 40
- **Length:** 83.3 m (273 ft)
- **Wingspan:** 25.4 m (82 ft)
- **Height:** ()
- **Empty weight:** 53,000 kg (120,000 lb)
- **Loaded weight:** 345,000 kg (760,000 lb)
- **Powerplant:** 2× SABRE synergistic combined cycle jet engine

- **Dry thrust:** 2,700 LT; 3,000 ST (2,700 LT; 3,000 ST) each
- **Thrust with afterburner:** 3,500 LT; 4,000 ST (3,500 LT; 4,000 ST) each

Performance

- **Maximum speed:** orbital
- **Range:** orbital ()
- **Service ceiling:** 26,000 m air breathing, >200 km exoatmospheric (85,000 ft air breathing, >124 mi exoatmospheric)
- **Thrust/weight:** ~1.2 – 3 at burnout (~0.768 atmospheric)SSTO

- Fuselage diameter: 6.75 m (22.15 ft)
- Maximum payload mass: 12,000 kg (26,000 lb)
- Specific impulse: 3560 s (35 kN·s/kg) atmospheric, 450 s (4.4 kN·s/kg) exoatmospheric
- SABRE engine thrust/weight ratio: up to 14 atmospheric

Chapter 16

Nuclear Aircraft

A **nuclear aircraft** is an aircraft powered by nuclear energy. Research into them was pursued during the Cold War by the United States and the Soviet Union as they would presumably allow a country to keep nuclear bombers in the air for extremely long periods of time, a useful tactic for nuclear deterrence. Neither country created any nuclear aircraft in production numbers. One design problem, never adequately solved, was the need for heavy shielding to protect the crew from radiation sickness.

Unmanned missiles have been designed to use nuclear thermal rockets, but such designs were considered too dangerous for crews to actually fly.



The only US aircraft to carry a nuclear reactor was the NB-36H. The program was canceled in 1958

U.S. programs

NEPA and ANP

In May, 1946, the Nuclear Energy for the Propulsion of Aircraft (NEPA) project was started by the United States Air Force. Studies under this program were done until May, 1951 when NEPA was replaced by the Aircraft Nuclear Propulsion (ANP) program. The ANP program included provisions for studying two different types of nuclear-powered jet engines, General Electric's Direct Air Cycle and Pratt & Whitney's Indirect Air Cycle. ANP also contained plans for two B-36s to be modified by Convair under the **MX-1589** project, one of the B-36s was to be used to study shielding requirements for an airborne reactor while the other was to be the X-6. The program was cancelled before the X-6 was completed, however.

The Oak Ridge National Laboratory conducted research (Aircraft Reactor Experiment) to produce a nuclear powered aircraft. Two General Electric turbofan engines were successfully powered to nearly full thrust using two shielded reactors. The two engines complete with reactor system are currently located at the EBR-1 facility south of the Idaho National Laboratory.



Experimental HTRE reactors for nuclear aircraft, on display at Idaho National Laboratory near Arco, Idaho.

The U.S. designed these engines to be used in a new specially designed nuclear bomber, the WS-125. The WS-125 was eventually terminated by Eisenhower who cut NEPA and told Congress that there was no urgency for the program. Eisenhower did back a small scale program developing high temperature materials and high performance reactors. That program was terminated early in the Kennedy administration.

Project Pluto

In 1957, the Air Force and the U.S. Atomic Energy Commission contracted with the Lawrence Radiation Laboratory to study the feasibility of applying heat from nuclear reactors to ramjet engines. This research became known as *Project Pluto*. The engines being developed under this program were intended to power an unmanned cruise missile, called SLAM, for Supersonic Low Altitude Missile. The program succeeded in producing two test engines which were operated on the ground. On May 14, 1961, the world's first nuclear ramjet engine, "Tory-IIA," mounted on a railroad car, roared to life for just a few seconds. On July 1, 1964, seven years and six months after it was born, "Project Pluto" was cancelled.

Soviet programs

Soviet Nuclear Bomber hoax

The 1 December 1958 issue of *Aviation Week* included an article, *Soviets Flight Testing Nuclear Bomber*, that claimed that the Soviets had made great progress in their own nuclear aircraft program. This was accompanied by an editorial on the topic as well. The magazine claimed that the aircraft was real beyond a doubt, stating that "A nuclear-powered bomber is being flight tested in the Soviet Union. Completed about six months ago, this aircraft has been flying in the Moscow area for at least two months. It has been observed both in flight and on the ground by a wide variety of foreign observers from Communist and non-Communist countries." Unlike the US designs of the same era, which were purely experimental, the article noted that "The Soviet aircraft is a prototype of a design to perform a military mission as a continuous airborne alert warning system and missile launching platform."

Photographs illustrated the article, along with technical diagrams on the proposed layout. They were so widely seen that one company produced a plastic model aircraft, a surprisingly faithful rendition of the diagrams in the article.

Concerns were soon expressed in Washington that "*the Russians were from three to five years ahead of the US in the field of atomic aircraft engines and that they would move even further ahead unless the US pressed forward with its own program*". This led to continued funding of the US's own program, for a time.

In reality the entire article was a hoax. The aircraft in the photographs was later revealed to be the entirely conventional Myasishchev M-50 *Bounder*, a medium-range strategic bomber with performance similar to the USAF's B-58 Hustler. The design was considered

a failure and never entered service. The design was revealed to the public on Soviet Aviation Day in 1963 at Monino, putting the issue to rest.

Tupolev Tu-119

The Soviet program of developing nuclear aircraft resulted in the experimental Tupolev Tu-119, also known as the Tu-95LAL (LAL- Летаящая Атомная Лаборатория- Flying Nuclear Laboratory). It was based on a Tupolev Tu-95 bomber. It had 4 conventional turboprop engines and an onboard nuclear reactor. The Tu-119 completed 34 research flights. Most of these were made with the reactor shut down. The main purpose of the flight phase was examining the effectiveness of the radiation shielding which was one of the main concerns for the engineers. Massive amounts of protection used resulted in radiation levels low enough to consider continuing development. But, as in the US, development never continued past this point. The obvious potential of the ICBM made the expensive program superfluous, and around the mid 1960s it was cancelled.

Chapter 17

Aircraft Nuclear Propulsion and Convair X-6

Aircraft Nuclear Propulsion



HTRE 3, left, and HTRE 1, right, on display at the Idaho National Laboratory near Arco, Idaho

The **Aircraft Nuclear Propulsion (ANP)** program and the preceding **Nuclear Energy for the Propulsion of Aircraft (NEPA)** project worked to develop a nuclear propulsion system for aircraft. The United States Army Air Force initiated **Project NEPA** on May

28, 1946. After funding of \$10 million in 1947, NEPA operated until May 1951, when the project was transferred to the joint Atomic Energy Commission (AEC)/USAF ANP. The USAF pursued two different systems for nuclear powered jet engines, the **Direct Air Cycle** concept which was developed by General Electric, and **Indirect Air Cycle** which was assigned to Pratt & Whitney. The program was intended to develop and test the Convair X-6, but was cancelled in 1961 before that aircraft was built.

Direct Air Cycle program



Aircraft Reactor Experiment building at ORNL

The General Electric program, which was based at Evendale, Ohio, was pursued because of its advantages in simplicity, reliability, suitability and quick start ability. Conventional

jet engine compressor and turbine sections were used, with the compressed air run through the reactor itself to heat it before being exhausted through the turbine.

The US *Aircraft Reactor Experiment (ARE)* was a 2.5 MW thermal nuclear reactor experiment designed to attain a high power density for use as an engine in a nuclear powered bomber. It used the molten fluoride salt NaF-ZrF₄-UF₄ (53-41-6 mol%) as fuel, was moderated by beryllium oxide (BeO), used liquid sodium as a secondary coolant and had a peak temperature of 860 °C. It operated for a 1000-hour cycle in 1954. It was the first molten salt reactor. Work on this project in the US stopped after ICBMs made it obsolete. The designs for its engines can currently be viewed at the EBR-I memorial building at the Idaho National Laboratory.

In 1955, this program produced the successful X-39 engine, two modified General Electric J47s with heat supplied by the Heat Transfer Reactor Experiment-1 (HTRE-1). The HTRE-1 was replaced by the HTRE-2 and eventually the HTRE-3 unit powering the two J47s. The HTRE-3 used "a flight-type shield system" and would probably have gone on to power the X-6 had that program been pursued.

Indirect Air Cycle program

The Indirect Air Cycle program was assigned to Pratt & Whitney, at a facility near Middletown, Connecticut. This concept would have produced far less radioactive pollution. One or two loops of liquid metal would carry the heat from the reactor to the engine. This program involved a great deal of research and development of many light-weight systems suitable for use in aircraft, such as heat exchangers, liquid-metal turbopumps and radiators. The Indirect Cycle program never came anywhere near producing flight-ready hardware.

MX-1589 project

On September 5, 1951, the USAF awarded Consolidated-Vultee a contract to fly a nuclear reactor onboard a modified Convair B-36 under the MX-1589 project of the ANP program. The NB-36H Nuclear Test Aircraft (NTA) was to study shielding requirements for an airborne reactor, to determine whether a nuclear aircraft was feasible. This was the only known airborne reactor experiment by the U.S. with an operational nuclear reactor on board. The NTA flew a total of 47 times testing the reactor over West Texas and Southern New Mexico. The reactor, named the Aircraft Shield Test Reactor (ASTR), was operational but did not power the plane, rather the primary purpose of the flight program was shield testing.

Convair X-6

Convair X-6



Convair NB-36H flying nuclear reactor testbed

Role	Experimental aircraft
Manufacturer	Convair
First flight	Not flown
Status	Cancelled
Primary user	USAF
Number built	1 (for weight tests only)
Developed from	Convair B-36



Convair NB-36H, flying testbed for X-6 project

The **Convair X-6** was a proposed experimental aircraft project to develop and evaluate a nuclear-powered jet aircraft. The project was to use a Convair B-36 bomber as a testbed aircraft, and though one NB-36H was modified during the early stages of the project, the program was cancelled before the actual X-6 and its nuclear reactor engines were completed. The X-6 was part of a larger series of programs, costing US\$7 billion in all, that ran from 1946 through 1961. Because such an aircraft's range would not have been limited by liquid jet fuel, it was theorized that nuclear-powered strategic bombers would be able to stay airborne for weeks at a time.

History

In May, 1946, the Nuclear Energy for the Propulsion of Aircraft (NEPA) project was started by the Air Force. Studies under this program were done until May, 1951 when NEPA was replaced by the Aircraft Nuclear Propulsion (ANP) program. The ANP program contained plans for two B-36s to be modified by Convair under the **MX-1589** project. One of the B-36s was to be used to study shielding requirements for an airborne reactor while the other was to be the X-6.

Nuclear Test Aircraft

The first modified B-36 was called the Nuclear Test Aircraft (NTA), a B-36H-20-CF (Serial Number 51-5712) that had been damaged in a tornado at Carswell AFB on September 1, 1952. This plane was redesignated the XB-36H, then the NB-36H and was

modified to carry a 3 megawatt, air-cooled nuclear reactor in its bomb bay. The reactor, named the Aircraft Shield Test Reactor (ASTR), was operational but did not power the plane. Water, acting as both moderator and coolant, was pumped through the reactor core and then to water-to-air heat exchangers to dissipate the heat to the atmosphere. Its sole purpose was to investigate the effect of radiation on aircraft systems.

To shield the flight crew, the nose section of the aircraft was modified to include a 12-ton lead and rubber shield. The standard windshield was replaced with one made of 6-inch-thick acrylic glass. The amount of lead and water shielding was variable. Measurements of the resulting radiation levels were then compared with calculated levels to enhance the ability to design optimal shielding with minimum weight for nuclear-powered bombers.

The NTA completed 47 test flights and 215 hours of flight time (during 89 of which the reactor was operated) between September 17, 1955, and March 1957 over New Mexico and Texas. This was the only known airborne reactor experiment by the U.S. with an operational nuclear reactor on board. The NB-36H was scrapped at Fort Worth in 1958 when the Nuclear Aircraft Program was abandoned. After the ASTR was removed from the NB-36H, it was moved to the National Aircraft Research Facility.

Based on the results of the NTA, the X-6 and the entire nuclear aircraft program was abandoned in 1961.

Development plans



Experimental Breeder Reactor Number 1 in Idaho, the first power reactor. The reactor is in the building top right, the two structures lower left are reactors from the Aircraft Nuclear Propulsion Project

Had the program progressed, follow-on aircraft would have been based on the successor to the B-36, Convair's swept-wing B-60.

The X-6 would have been powered by General Electric X-39 engines, utilizing a P-1 reactor. In a nuclear jet engine, the reactor core was used as a heat source for the turbine's air flow, instead of burning jet fuel. One disadvantage of the design was that, since the airflow through the engine was used to cool the reactor, this airflow had to be maintained even after the aircraft had landed and parked. GE built two prototype engines, which can be seen outside the Experimental Breeder Reactor I in Arco, Idaho.

A large, 350-foot (106.7 meter-) wide hangar was built at Test Area North, part of the National Reactor Testing Station (now part of the Idaho National Laboratory), Monteview, Idaho to house the X-6 project, but the project was cancelled before the planned 15,000-foot (4,572m) runway was built. The length was necessitated by the expected weight of the nuclear-powered aircraft.

Soviet program

In the 1960s, the Soviet Union's Tupolev design bureau conducted a similar experiment using a Tupolev Tu-119, which was a Tu-95 bomber modified to carry an operational reactor.

Specifications (NB-36H)

General characteristics

- **Crew:** Five
- **Length:** 162 ft (49.38 m)
- **Wingspan:** 230 ft (70.1 m)
- **Height:** 46 ft 9 in (14.26 m)
- **Wing area:** 4,770 ft² (443.3 m²)
- **Max takeoff weight:** 360,000 lb (163,000 kg)
- **Powerplant:**
 - 4× General Electric X40 turbojets, () each
 - 6× Pratt & Whitney R-4360-53, 3,800 hp (2,830 kW) each

Performance

- **Maximum speed:** 390 mph (628 km/h)
- **Service ceiling:** 40,000 ft (12,200 m)

Chapter 18

Convair B-36

B-36 "Peacemaker"



The B-36D used both piston and jet engines.

Role	Strategic bomber
Manufacturer	Consolidated Vultee
Designed by	Ted Hall
First flight	8 August 1946
Introduced	1949
Retired	12 February 1959
Primary user	United States Air Force
Number built	384
Unit cost	US\$4.1 million (B-36D) (\$37.8 million in today's dollars)
Variants	Convair YB-60 Convair XC-99 Convair X-6 (Unbuilt)

The **Convair B-36 "Peacemaker"** was a strategic bomber built by Convair and operated solely by the United States Air Force (USAF) from 1949 to 1959. The B-36 was the largest mass-produced piston engine aircraft ever made. It had the longest wingspan of any combat aircraft ever built (230 ft or 70 m), although there have been larger military

transports. The B-36 was the first bomber capable of delivering any of the nuclear weapons in the US arsenal from inside its two bomb bays without aircraft modifications. With a range greater than 6,000 mi (9,700 km) and a maximum payload of 72,000 lb (33,000 kg), (and thereby having the ability to carry both the US's atomic fission and fusion weapons), the B-36 was the world's first manned bomber with an unrefueled intercontinental range.

Development

The genesis of the B-36 can be traced to early 1941, prior to the entry of the U.S. into World War II. At the time it appeared there was a very real chance that Britain might fall to the Nazi 'Blitz', making a strategic bombing effort by the United States Army Air Corps (USAAC) against Germany impossible with the aircraft of the time. The U.S. would need a new class of bomber that could reach Europe from bases in North America, necessitating a combat range of at least 5,700 miles (9,200 km), the length of a Gander, Newfoundland–Berlin round trip. The USAAC therefore sought a bomber of truly intercontinental range, similar to the Nazi RLM's own ultra-long-range *Amerika Bomber* program.

The USAAC opened up a design competition for the very long-range bomber on 11 April 1941, asking for a 450 mph (720 km/h) top speed, a 275 mph (443 km/h) cruising speed, a service ceiling of 45,000 ft (14,000 m), beyond the range of ground-based anti-aircraft fire, and a maximum range of 12,000 miles (19,000 km) at 25,000 ft (7,600 m). These proved too demanding—far exceeding the technology of the day—for any short-term design, so on 19 August 1941 they were reduced to a maximum range of 10,000 mi (16,000 km), an effective combat radius of 4,000 mi (6,400 km) with a 10,000 lb (4,500 kg) bombload, a cruising speed between 240 and 300 mph (390 and 480 km/h), and a service ceiling of 40,000 ft (12,000 m).

Experimentals and prototypes



The huge new XB-36 alongside the first superbomber, the B-29 Superfortress. The wings of the 'Peacemaker' were 7 feet (2.1 m) thick at the root.



The XB-36 taking off. Production aircraft had four-wheel main gear instead of the giant single tires seen on the prototype aircraft.

Consolidated Vultee Aircraft Corporation (later Convair) and Boeing Aircraft Company took part in the competition, with Consolidated winning a tender on 16 October 1941. Consolidated asked for a \$15 million contract with \$800,000 for research and development, mock-up, and tooling. Two experimental bombers were proposed, the first to be delivered in 30 months, and the second within another six months. Originally designated Model B-35, the name was changed to B-36 to avoid confusion with the Northrop YB-35.

Throughout its development, the B-36 would encounter various delays. When the United States entered World War II on 7 December 1941, Consolidated was ordered to slow down the B-36 project and increase production of the B-24 Liberator. The first mockup was inspected on 20 July 1942, following six months of refinements. A month after the mockup inspection the project was moved from San Diego, California to Fort Worth, Texas, which set back development several months. Consolidated changed the tail from a twin-tail to a single, thereby saving 3,850 pounds, but this change would delay delivery by 120 days. The tricycle landing gear system's initial main gear design, incorporating huge single wheels that would quickly be found to cause significant ground pressure problems, only allowed the B-36 to land at just three airports in the United States (Fort Worth, Eglin Field, Florida, and Fairfield-Suisun Field (now Travis AFB) in California), mandated that Consolidated design a four-wheeled truck-type wheel arrangement for the main gear instead, which distributed the weight more evenly and reduced weight by 1,500 lb. Changes in the United States Army Air Forces (USAAF) requirements would add back any weight saved in redesigns, and cost more time. A new antenna system needed to be designed to accommodate an ordered radio and radar system. The Pratt & Whitney engines were redesigned, adding another 1,000 lb.

World War II and after

Early in the war, the military refused to supply materials, tradespeople, and engineers to the project, which slowed work. As the Pacific war progressed, the United States increasingly needed a bomber capable of reaching Japan from its bases in Hawaii, and the B-36 began its development in earnest again. Secretary of War Henry L. Stimson, in discussions with high ranking officers of the AAF, decided to waive normal Army procurement procedures, and on 23 July 1943 ordered 100 B-36s before the completion and testing of the two prototypes. The first delivery was due in August 1945, and the last in October 1946, but Consolidated (now renamed Convair) delayed delivery. The aircraft was unveiled on 20 August 1945, and flew for the first time on 8 August 1946.

After the Cold War began in earnest with the 1948 Berlin Airlift and the 1949 atmospheric test of the first Soviet atomic bomb, American military planners sought bombers capable of delivering the very large and heavy first-generation atomic bombs. The B-36 was the only American aircraft with the range and payload to carry such bombs from airfields on American soil to targets in the USSR. (Storing nuclear weapons in foreign countries was, and remains, diplomatically sensitive and risky).

The B-36 was arguably obsolete from the outset, being piston-powered, particularly in a world of super-sonic jet interceptors, but its jet rival, the B-47 Stratojet, which did not become fully operational until 1953, lacked the range to attack the Soviet homeland from North America and could not carry the huge first-generation hydrogen bomb. Nor could the other American piston bombers of the day, the B-29 or B-50. Intercontinental ballistic missiles (ICBMs) did not become effective deterrents until the 1960s. Until the B-52 Stratofortress became operational in the late 1950s, the B-36, as the only truly intercontinental bomber, continued to be the primary nuclear weapons delivery vehicle of the Strategic Air Command (SAC).

Convair touted the B-36 as the "aluminum overcast", a so-called "long rifle" giving SAC truly global reach. While General Curtis LeMay headed SAC (1949–57), he turned the B-36 arm, through intense training and development, into an effective nuclear delivery force, forming the heart of the Strategic Air Command. Its maximum payload was more than four times that of the B-29, even exceeding that of the B-52. The B-36 was slow and could not refuel in midair, but could fly missions to targets 3,400 mi (5,500 km) away and stay aloft as long as 40 hours. Moreover, the B-36 was believed to have "an ace up its sleeve": a phenomenal cruising altitude for a piston-driven aircraft, made possible by its huge wing area and six 28-cylinder engines, putting it out of range of all piston fighters, early jet interceptors, and ground batteries.

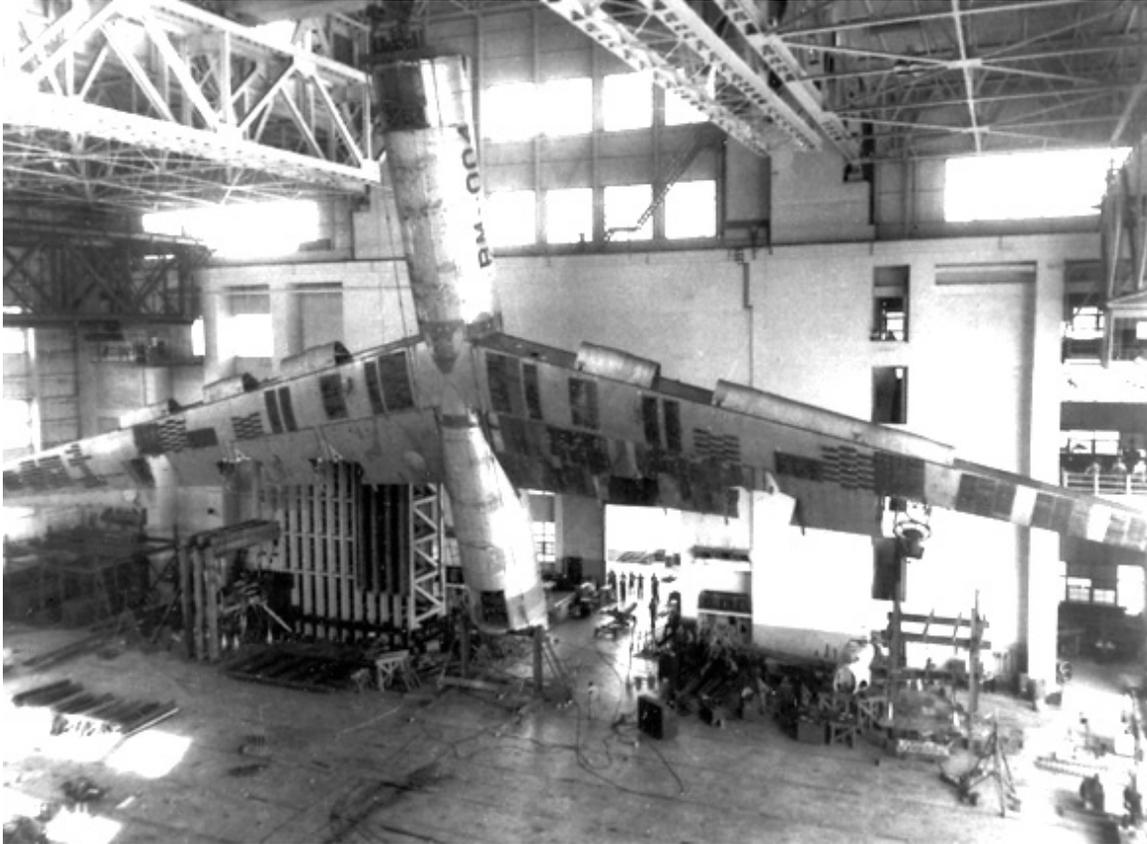
Operating and financial problems

The B-36 was difficult to operate, prone in its early service years to catastrophic engine fires, electrical failures, and other costly malfunctions. In later years, inaccessible fuel and oil leaks were problems. To its critics, these problems made it a "billion-dollar blunder". In particular, the United States Navy saw it as a costly bungle, diverting Congressional funding and interest from naval aviation and aircraft carriers in general, and carrier-based nuclear bombers in particular. In 1947, the Navy attacked Congressional funding for the B-36, alleging it failed to meet Pentagon requirements. The U.S. Navy held to the preeminence of the aircraft carrier in the Pacific during World War II, presuming carrier-based aircraft would be decisive in future wars. To this end, the Navy designed the USS *United States* (CVA-58), a "supercarrier" capable of launching huge fleets of tactical aircraft or nuclear bombers. It then pushed to have funding transferred from the B-36 to the USS *United States*. The Air Force successfully defended the B-36 project, and the *United States* was officially cancelled by Secretary of Defense Louis A. Johnson in a cost-cutting move. Several high-level Navy officials questioned the government's decision, alleging a conflict of interest because Johnson had once served on Convair's Board of Directors. The uproar following the cancellation of *United States* was nicknamed the "Revolt of the Admirals".

The furor, as well as the significant use of aircraft carriers in the Korean War, resulted in the design and procurement of the subsequent *Forrestal* class of supercarriers, which were of comparable size to the *United States* but with a design geared towards greater multirole use with composite air wings of fighter, attack, reconnaissance, electronic warfare, early warning and anti-submarine warfare aircraft. At the same time, heavy

manned bombers for the Strategic Air Command were also deemed crucial to national defense and, as a result, the two systems were never again in competition for the same budgetary resources.

Design



An B-36 airframe undergoing structural stability tests. Note for scale the three men at the extreme right of the photograph

The B-36 took shape as an aircraft of immense proportions. It was two-thirds longer than the previous "superbomber", the B-29. The wingspan and tail height of the B-36 exceeded those of the Antonov An-22, the largest ever mass-produced propeller-driven aircraft. Only with the advent of the Boeing 747 and the Lockheed C-5 Galaxy, both designed two decades later, did aircraft capable of lifting a heavier payload become commonplace.

The wings of the B-36 were large even when compared with present-day aircraft, exceeding, for example, those of the C-5 Galaxy, and enabled the B-36 to carry enough fuel to fly very long missions without refueling. The widest point around the chord of the wing was seven and a half feet thick containing a crawlspace that allowed crew access to the engines. The wing area permitted cruising altitudes well above the operating ceiling of any 1940s-era piston and jet-turbine fighters. All versions of the B-36 could cruise at over 40,000 ft (12,000 m). B-36 mission logs commonly recorded mock attacks against

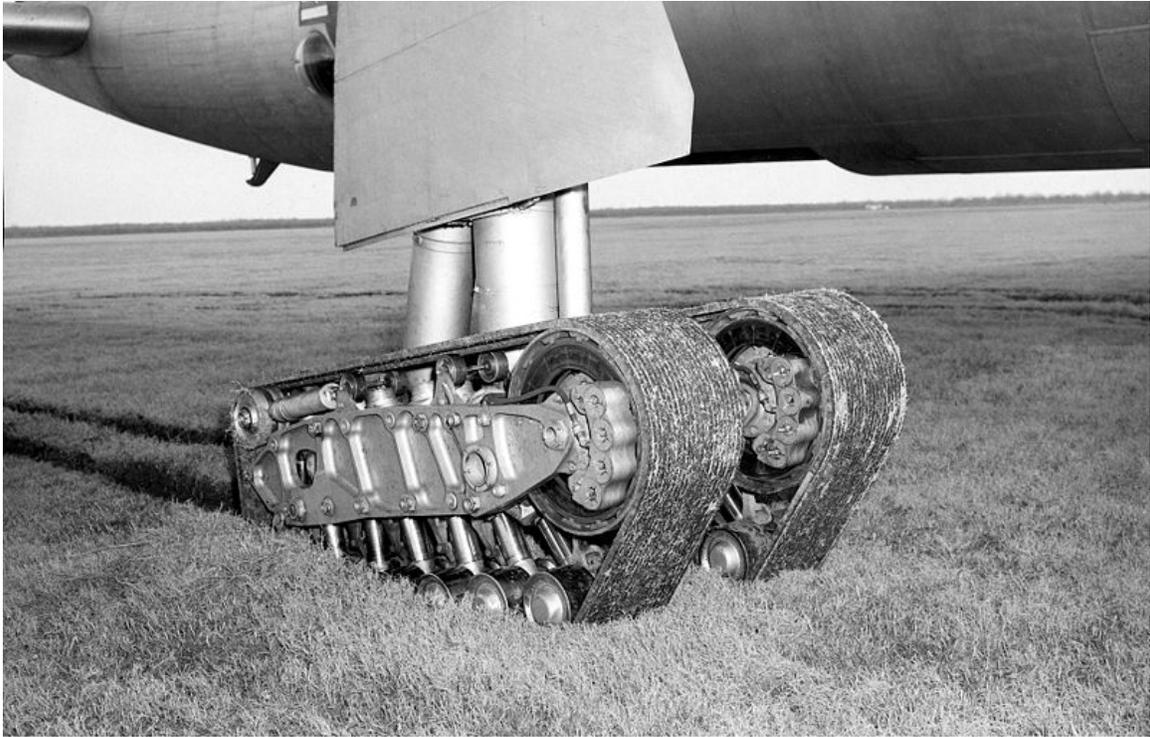
U.S. cities while flying at 49,000 ft. In 1954, the turrets and other nonessential equipment were removed, resulting in a "featherweight" configuration believed to have resulted in a top speed of 423 mph (700 km/h), and cruise at 50,000 ft (15,000 m) and dash at over 55,000 ft (16,800 m), perhaps even higher.

The large wing area and the option of starting the four jet engines gave the B-36 a wide margin between stall speed (V_S) and maximum speed (V_{max}) at these altitudes. This made the B-36 more maneuverable at high altitude than the USAF jet interceptors of the day, which either could not fly above 40,000 ft (12,000 m), or if they did, were likely to stall out when trying to maneuver or fire their guns. However, the Navy argued that their F2H Banshee fighter could intercept the B-36, thanks to its ability to operate at more than 50,000 ft (15,000 m). The Air Force declined the Navy's invitation to a fly-off between the Banshee and the B-36. Later, the new Secretary of Defense, Louis A. Johnson, who considered the U.S. Navy and Naval Aviation essentially obsolete in favor of the U.S. Air Force and Strategic Air Command, forbade putting the Navy's claim to the test.

The propulsion system alone made the B-36 a very unusual aircraft. All B-36s featured six 28-cylinder Pratt & Whitney R-4360 'Wasp Major' radial engines. Even though the prototype R-4360s delivered a total of 18,000 hp (13 MW), early B-36s were slow and required long takeoff runs. The situation improved with later versions delivering 3,800 hp (2.8 MW) apiece. Each engine drove an immense three-bladed propeller, 19 ft (5.8 m) in diameter, mounted in the pusher configuration. This unusual configuration prevented propeller turbulence from interfering with airflow over the wing, but also led to chronic engine-overheating due to insufficient airflow around the engines, resulting in numerous in-flight engine fires.

Beginning with the B-36D, Convair added a pair of General Electric J47-19 jet engines suspended near the end of each wing; these were also retrofitted to all extant B-36Bs. Thus the B-36 came to have 10 engines ("six turnin' and four burnin' ", as said by American airmen), more than any other mass-produced aircraft. The jet pods greatly improved takeoff performance and dash speed over the target. In normal cruising flight, the jet engines were shut down to conserve fuel. The two pods with four turbojets and the six piston engines combined gave the B-36 a total of 40,000 hp for short periods of time.

The B-36 had a crew of 15. As in the B-29, the pressurized flight deck and crew compartment were linked to the rear compartment by a pressurized tunnel through the bomb bay. In the B-36, one rode through the tunnel on a wheeled trolley, by pulling oneself on a rope. The rear compartment featured six bunks and a dining galley, and led to the tail turret. The B-36 also tested the experimental Boston Camera.



Closeup of experimental tracked landing gear

The XB-36 featured a single-wheel landing gear whose tires were the largest ever manufactured up to that time, 9 ft 2 in (2.7 m) tall, 3 ft (1 m) wide, and weighing 1,320 lb (600 kg), with enough rubber for 60 automobile tires. These tires placed so much weight per unit area on runways, the XB-36 was restricted to the Fort Worth airfield adjacent to the plant of manufacture, and to a mere two USAF bases beyond that. At the suggestion of General Arnold, the single-wheel gear was soon replaced by a four-wheel bogie. At one point a tank-like tracked landing gear was also tried on the XB-36, but proved heavy and noisy and was quickly abandoned.

Weaponry

The four bomb bays could carry up to 86,000 lb (39 metric tons) of bombs, more than 10 times the load carried by the World War II workhorse, the B-17 Flying Fortress, and substantially more than the entire B-17's gross weight. The B-36 was not designed with nuclear weaponry in mind, because the mere existence of such weapons was top secret during the period when the B-36 was conceived and designed (1941–46). Nevertheless, the B-36 stepped into its nuclear delivery role immediately upon becoming operational. In all respects except speed, the B-36 could match what was arguably its approximate Soviet counterpart, the Tu-95, which began production in January 1956 and at the time of this writing is still in service. Until the B-52 came on line, the B-36 was the only means of delivering the first generation Mark-17 hydrogen bomb, 25 ft (7.5 m) long, 5 ft (1.5 m) in diameter, and weighing 42,000 lb (19,000 kg), the heaviest and bulkiest American

aerial nuclear bomb ever. Carrying this massive weapon required merging two adjacent bomb bays.

The defensive armament consisted of six remote-controlled retractable gun turrets, and fixed tail and nose turrets. Each turret was fitted with two 20 mm cannons, for a total of 16 cannons, the greatest defensive gunnery ever carried by any aircraft. Recoil vibration from gunnery practice often caused the airplane's electrical wiring to jar loose or the vacuum tube electronics to malfunction, leading to failure of the aircraft controls and navigation equipment. This contributed to the crash of B-36B 44-92035 on 22 November 1950.



B-36 upper or lower gun turret with 2x 20 mm M-24A1 cannon

The Convair B-36 was the only aircraft designed to carry the T-12 Cloudmaker, a gravity bomb weighing 43,600 lb (19,800 kg) and designed to produce an earthquake bomb effect. The first prototype XB-36 flew on 8 August 1946. The speed and range of the prototype failed to meet the standards set out by the Army Air Corps in 1941. This was expected, as the engines required (Pratt & Whitney R-4360s) were not yet available, and the lack of qualified workers and materials needed to install them prevented Convair from achieving its goals.

A second aircraft, the YB-36, flew on 4 December 1947. It featured a redesigned high visibility bubble canopy, which was later adopted for production. Altogether, the YB-36 was much closer to the production aircraft. Additionally, the engines used on the YB-36 were a good deal more powerful and more efficient.



The XB-36 on its first flight.

The first of 21 B-36As were delivered in 1948. They were admittedly interim airframes, intended for crew training and later conversion. No defensive armament was fitted as none was ready. Once later models were available, all B-36As were converted to RB-36E reconnaissance models. The first B-36 variant meant for normal operation was the B-36B, delivered beginning in November 1948. This aircraft met all the 1941 requirements, but had serious problems with engine reliability and maintenance (changing the 336 spark plugs was a task dreaded by ground crews), and with the availability of armaments and spare parts. Later models featured more powerful variants of the R-4360 engine, improved radar, and redesigned crew compartments.

The four jet engines raised fuel consumption, thus reducing range. Meanwhile, the advent of air-to-air missiles rendered conventional gun turrets obsolete. In February 1954, the USAF awarded Convair a contract reducing the weight of the entire B-36 fleet by implementing a new "Featherweight" design program in three configurations:

- Featherweight I removed the six movable gun turrets and other defensive hardware.
- Featherweight II removed the rear compartment crew comfort features, and all hardware accommodating the XF-85 parasite fighter.

- Featherweight III incorporated both configurations I and II.

The six turrets eliminated by Featherweight I reduced the aircraft's crew from 15 to 9. Featherweight III enabled a longer range and an operating ceiling of at least 47,000 ft (14,000 m), features especially valuable for reconnaissance missions. The B-36J-III configuration (the last 14 made) featured a single radar-aimed tail turret, extra fuel tanks in the outer wings, and landing gear allowing the maximum gross weight to rise to 410,000 lb (190,000 kg). Production of the B-36 ceased in 1954.

Operational history



RB-36D

The B-36, including its GRB-36, RB-36, and XC-99 variants, was in service as part of the USAF Strategic Air Command from 1948 through 1959. The B-36 never dropped a bomb or fired a shot in active service.

Maintenance



Personnel and equipment required to get and keep a B-36 aircraft in the air

The B-36 was too large to fit in most hangars. Moreover, even an aircraft with the range of the B-36 needed to be stationed as close to the enemy as possible, and this meant the northern continental United States, Alaska, and the Arctic. As a result, most "normal" maintenance, such as changing the 56 spark plugs (always at risk of fouling by the leaded fuel of the day) on each of its six engines, or replacing the dozens of bomb bay light bulbs shattered after a gunnery mission, was performed outdoors, in 100 °F (38 °C) summers or -60 °F (-51 °C) winters, depending on the location. Special shelters were built so that the maintenance crews could enjoy a modicum of protection while working on the engines. Often, ground crews were at risk of slipping and falling from icy wings, or being blown off the wings by a propeller running in reverse pitch.

The wing roots were thick enough, at 7 ft (2.1 m), to enable a flight engineer to access the engines and landing gear by crawling through the wings. This was possible only at altitudes not requiring pressurization.

The Wasp Major engines also had a prodigious appetite for lubricating oil, each engine requiring its own 100 gal (380 l) tank.((cn))

Engine fires

Much more than other large aircraft powered by piston engines, the B-36 was very prone to engine fires, to the extent that some crews changed the phrase "six turning, four burning" into "two turning, two burning, two smoking, two joking, and two unaccounted for". This problem was exacerbated by the propellers' pusher configuration, which increased carburetor icing. The design of the R-4360 engine tacitly assumed that it would be mounted in the conventional tractor configuration—propeller/air intake/28 cylinders/carburetor—with air flowing in that order. In this configuration, the carburetor is bathed in warmed air flowing past the engine, and so is unlikely to ice up. However, the R-4360 engines in the B-36 were mounted backwards, in the pusher configuration—air intake/carburetor/28 cylinders/propeller. The carburetor was now in front of the engine and so could not benefit from engine heat, and also made more traditional short term carburetor heat systems unsuitable. Hence, when intake air was cold and humid, ice gradually obstructed the carburetor air intake, which in turn gradually increased the richness of the air/fuel mixture until the unburned fuel in the exhaust caught fire. Three engine fires of this nature led to the first loss of an American nuclear weapon, described below.

Crew experience

Training missions were typically in two parts; first, a 40 hour flight—followed by some time on the ground for refueling and maintenance—then a 24 hour second flight. With a sufficiently light load, the B-36 could fly at least 10,000 mi (16,000 km) nonstop, and the highest cruising speed of any version, the B-36J-III, was only 230 mph (380 km/h). Turning the jet engines on could raise the cruising speed to over 400 mph (650 km/h), but the resulting higher fuel consumption reduced the range. Hence a 40-hour mission, with the jets used only for takeoff and climbing, flew about 9,200 mi (15,000 km).

The B-36 was not a particularly enjoyable aircraft to fly. Its overall performance, in terms of speed and maneuverability, was never considered sprightly. Lieutenant General James Edmundson likened it to "...sitting on your front porch and flying your house around." Despite its immense exterior size, the pressurized crew compartments were relatively cramped, especially when occupied for 24 hours by a crew of 15 in full flight kit.

War missions would have been essentially one-way, taking off from forward bases in Alaska or Greenland, overflying the USSR, and landing in Europe, North Africa (Morocco), or the Middle East. Ironically, recollections of crew veterans reveal that while crews were confident of their ability to complete a mission if called upon to do so, they were less confident of surviving the weapon delivery itself. Their concerns were a function of the relatively low speed of the aircraft coupled with the extreme destructive power of the bombs they were carrying, resulting in the aircraft still being within blast range once the bombs detonated on target. These concerns were borne out by the 1954 Operation Castle tests, in which B-36s flew near detonations in the 15-megaton range, at distances believed typical of wartime delivery, and experienced extensive blast damage.

Experiments



NB-36H nuclear reactor testbed



GRB-36 carrying YRF-84F modified for FICON test. USAF Museum Photo Archives

The B-36 was employed in a variety of aeronautical experiments throughout its service life. Its immense size, range and payload capacity lent itself to use in research and development programs. These included nuclear propulsion studies, and "parasite" programs in which the B-36 carried smaller interceptors or reconnaissance aircraft.

In May 1946, the Air Force began the Nuclear Energy for the Propulsion of Aircraft (NEPA) project which was followed in May 1951 by the Aircraft Nuclear Propulsion (ANP) program. The ANP program required that Convair modify two B-36s under the MX-1589 project. One of the modified B-36s studied shielding requirements for an airborne reactor to determine whether a nuclear aircraft was feasible. The Nuclear Test Aircraft (NTA) was a B-36H-20-CF (serial number 51-5712) that had been damaged in a tornado at Carswell AFB on 1 September 1952. This aircraft, designated the XB-36H (and later NB-36H), was modified to carry a 1 MW, air-cooled nuclear reactor in the aft bomb bay, with a four-ton lead disc shield installed in the middle of the aircraft between the 1,000-kilowatt reactor and the cockpit. A number of large air intake and exhaust holes were installed in the sides and bottom of the aircraft's rear fuselage to cool the reactor in flight. On the ground, a crane would be utilized to remove the 35,000 pound reactor from the aircraft. To protect the crew, the highly-modified cockpit was encased in lead and rubber, with a 1-foot-thick (30 cm) leaded glass windshield. The reactor was operational but did not power the aircraft; its sole purpose was to investigate the effect of radiation on aircraft systems. Between 1955 and 1957, the NB-36H completed 47 test flights and 215 hours of flight time, during 89 of which the reactor was critical.

Other experiments involved providing the B-36 with its own fighter defense in the form of parasite aircraft carried partially or wholly in a bomb bay. One parasite aircraft was the rather miniscule McDonnell XF-85 Goblin, which docked using a trapeze system. The concept was tested successfully using a B-29 carrier, but docking proved difficult even for experienced test pilots. Moreover, the XF-85 was seen as no match for contemporary foreign powers' newly-developed interceptor aircraft in development and in service, consequently, the project was cancelled.

More successful was the FICON project, involving a modified B-36—called a GRB-36D "mothership"—and the RF-84K, a fighter modified for reconnaissance, in a bomb bay. The GRB-36D would ferry the RF-84K to the vicinity of the objective, whereupon the RF-84K would disconnect and begin its mission. Ten GRB-36Ds and 25 RF-84Ks were built and saw limited service in 1955-1956.

Projects TIP TOW and Tom-Tom involved docking F-84s to the wingtips of B-29s and B-36s. The hope was that the increased aspect ratio of the combined aircraft would result in a greater range. Project TIP TOW was canceled when the combination of two EF-84Ds and a specially modified test EB-29A crashed, killing everyone on all three aircraft. This accident was attributed to one of the EF-84Ds flipping over onto the wing of the EB-29A. Project Tom-Tom, involving RF-84Fs and a GRB-36D from the FICON project (redesignated JRB-36F), continued for a few months after this crash, but was also canceled due to the violent turbulence induced by the wingtip vortices of the B-36.

Strategic Reconnaissance



In late 1952 during the Korean War six 5th Strategic Reconnaissance Wing RB-36Ds were deployed to the 91st Strategic Reconnaissance Group. at Yokota AB, Japan. This was the first introduction of RB-36 to the Korean theater. While not employed in any combat missions over North Korea, these RB-36s conducted high altitude aerial reconnaissance over Chinese Manchurian and Soviet east Asian targets while attached to the 91st SRG.

One of the SAC's initial missions was to plan strategic aerial reconnaissance on a global scale. The first efforts were in photo-reconnaissance and mapping. Along with the photo-reconnaissance mission, a small electronic intelligence (ELINT) cadre was operating. Weather reconnaissance was part of the effort, as was Long Range Detection, the search for Soviet atomic explosions. In the late 1940s, strategic intelligence on Soviet capabilities and intentions was scarce. Before the development of the Lockheed U-2 high altitude spy plane and orbital reconnaissance satellites, technology and politics limited American reconnaissance efforts to the borders, and not the heartland, of the Soviet Union.

One of the essential criteria of the early postwar reconnaissance aircraft was the ability to cruise above 40,000 ft, a level determined by knowledge of the capability of Russian air defense radar. The main Russian air defense radar in the 1950s was the American supplied SCR-270, or locally made copies, which were only effective up to 40,000 ft – in theory, an aircraft cruising above this level would remain undetected.

The first aircraft, which put this theory to the test, was the RB-36D specialized photographic-reconnaissance version of the B-36D. It was outwardly identical to the

standard B-36D, but carried a crew of 22 rather than 15, the additional crew members being needed to operate and maintain the photographic reconnaissance equipment that was carried. The forward bomb bay in the bomber was replaced by a pressurized manned compartment that was filled with fourteen cameras. This compartment included a small darkroom where a photo technician could develop the film. The second bomb bay contained up to 80 T-86 photo flash bombs, while the third bay could carry an extra 3,000 gallon droppable fuel tank. The fourth bomb bay carried ferret ECM equipment. The defensive armament of 16 M-24A-1 20 mm cannons was retained. The extra fuel tanks increased the flight endurance to up to 50 hours. It had an operational ceiling of 50,000 ft. Later, a lightweight version of this aircraft, the RB-36-III, could even reach 58,000 ft. RB-36s were distinguished by the bright aluminium finish of the camera compartment (contrasting with the dull magnesium of the rest of the fuselage) and by a series of radar domes under the aft fuselage, varying in number and placement. When developed, it was the only American aircraft having enough range to fly over the Eurasian land mass from bases in the United States, and size enough to carry the bulky high resolution cameras of the day.

The standard RB-36D carried up to 23 cameras, primarily K-17C, K-22A, K-38, and K-40 cameras. A special 240-foot focal length camera was tested on 44-92088, the aircraft being redesignated ERB-36D. The long focal length was achieved by using a two-mirror reflection system. The camera was supposedly capable of resolving a golf ball at an altitude of 40,000 ft. This camera is now with the National Museum of the United States Air Force at Wright Patterson AFB.

The first RB-36D (44-92088) made its initial flight on 18 December 1949, only six months after the first B-36D had flown. It initially flew without the turbojets. The 28th Strategic Reconnaissance Wing based at Rapid City AFB (later renamed Ellsworth AFB), South Dakota received its first RB-36D on 3 June 1950. Due to severe materiel shortages, the new RB-36Ds did not become operationally ready until June 1951. The 24th and last RB-36D was delivered in May 1951. A total of 24 RB-36Ds were built. Some RB-36Ds were later modified to the featherweight configuration, in which all but the tail guns were removed. The crew was reduced from 22 to 19. These aircraft were redesignated as RB-36D-III. Modifications were carried out by Convair from February 1954 to November 1954.

In 1951 RB-36Ds, with a range of 9,300 miles, began probing the boundaries of the Soviet Arctic and were rather disturbed to find their on-board equipment indicating that they had been detected by Soviet radar - so much for the theory. However, detecting aircraft on ground-based radar was one thing, intercepting them was far more difficult. A number of overflights of Soviet bases in the arctic, particularly the new nuclear weapons test complex at Novaya Zemlya, were made by RB-36 aircraft operating from RAF Sculthorpe in England. RB-36s performed a number of rarely acknowledged reconnaissance missions and is suspected of having carried out numerous penetrations of Chinese (and Soviet) airspace under the direction of General Curtis LeMay.

In early 1950, Convair began conversion of the B-36As to the reconnaissance configuration. Included in the conversions was the sole YB-36 (42-13571). These converted examples were all redesignated RB-36E. The six R-4360-25 engines were replaced by six R-4360-41s. They were also equipped with the four J-47 jet engines that were fitted to the RB-36D. Its normal crew was 22, which included five gunners to man the 16 M-24A-1 20 mm cannon. The last conversion was completed in July 1951. Later, the USAF also bought 73 long-range reconnaissance versions of the B-36H under the designation RB-36H. 23 were accepted during the first six months of 1952, the last were delivered by September 1953. More than a third of all B-36 models were reconnaissance models.

Advances in Soviet air defense systems meant that the RB-36 became limited to flying outside of the borders of the Soviet Union, as well as Eastern Europe. By the mid 1950s, the jet-powered Boeing RB-47E was able to pierce Soviet airspace and conduct a variety of spectacular overflights of the Soviet Union. Some of these flights probed deep into the heart of the Soviet Union, taking a photographic and radar recording of the route attacking SAC bombers would follow to reach their targets. The risks involved in mounting these dangerous sorties over some of the most inhospitable terrain on earth speaks volumes for the courage and skill of the crews involved. Flights which involved penetrating mainland Russia were termed SENSINT (Sensitive Intelligence) missions. One RB-47 even managed to fly 450 miles inland and photograph the city of Igarka in Siberia.

As with the strategic bombardment versions of the B-36, the RB-36s were phased out of the SAC inventory beginning in 1956, the last being sent to Davis-Monthan in January 1959.

Obsolescence



YB-52 prototype at Carswell AFB, 1955 shown with a 7th Bomb Wing B-36

With the appearance of the Soviet MiG-15 in combat over North Korea in 1950, USAF propeller-driven bombers were rendered obsolete as strategic offensive weapons. Although the MiG-15 had limited range and lacked radar, the swept-wing Soviet jet carried heavy-caliber weapons and could fly faster and higher than the F-80C and F-84G, the B-29's straight-winged jet fighter escorts. During daylight, the MiG-15 could attack the propeller-driven B-29s with impunity, forcing the United States to switch the B-29 to night raids.

The B-36, along with the B-29/B-50 Superfortresses in the USAF inventory in the early 1950s, were all designed during World War II, prior to the jet age. It would take a new generation of swept-wing jet bombers, being able to fly higher and faster to effectively defeat the defense of the MiG-15 or subsequent Soviet-designed interceptors if the Cold War escalated into an armed conflict between the United States and Soviet Union.

With the end of fighting in Korea, President Eisenhower, who had taken office in January 1953, called for a "new look" at national defense. His administration chose to invest in the Air Force, especially Strategic Air Command. The Air Force retired nearly all of its B-29/B-50s to be replaced by the new Boeing B-47 Stratojet. By 1955 the Boeing B-52 Stratofortress swept-wing strategic jet bombers would be entering the inventory in substantial numbers, and the B-36s began to be replaced.

In addition to the obsolescence of the aircraft, other factors leading to the phaseout of the B-36 were:

- The Peacemaker was not designed for aerial refueling, and required intermediate refueling bases in order to reach its planned targets deep in the Soviet Union.
- Its slow speed made it vulnerable to Soviet jet interceptor aircraft, making long-range bombardment flights over Soviet territory extremely hazardous, seriously compromising its ability to reach its planned target and return.
- Radar-guided surface-to air missiles, such as the Soviet SA-2 Guideline, capable of reaching 65,600 ft (20,000 m), emerged.
- The B-36 airframe, especially the wings, proved vulnerable to metal fatigue.
- Inflight wing flexing led to fuel leakage, a common problem.

The scrapping of B-36s began in February 1956. Once replaced by B-52s, they were flown directly from operational squadrons to Davis-Monthan AFB, Arizona, where the Mar-Pak Corporation handled their reclamation and destruction. However, defense cutbacks in FY 1958 compelled the B-52 procurement process to be stretched out and the B-36 service life to be extended. The B-36s remaining in service were supported with components scavenged from planes sent to Davis-Monthan for scrapping. Further update work was undertaken by Convair at San Diego (Specialized Aircraft Maintenance, SAM-SAC) until 1957 to extend the life and capabilities of the B-36s. By December 1958, only 22 B-36s (all of them B-36Js) were still operational.

On 12 February 1959, the last B-36J (and the final J built by Convair-52-2827) left Biggs AFB, Texas, where it had been on duty with the 95th Heavy Bombardment Wing, and

was flown to Amon Carter Field in Fort Worth, where it was put on permanent display. Within two years, all but five B-36s (which had been saved for museum display) had been scrapped at Davis-Monthan AFB.

Variants

Variant Built

XB-36 1
YB-36 1
B-36A 22
XC-99 1
B-36B 62
B-36D 26
RB-36D 24
B-36F 34
RB-36F 24
B-36H 83
RB-36H 73
B-36J 33
YB-60 2

Total 385

XB-36

Prototype powered by six 3,000 hp (2,200 kW) R-4360-25 engines and unarmed, one built.

YB-36

Prototype, s/n 42-13571, with modified nose and raised cockpit roof, one built later converted to YB-36A.

YB-36A

Former YB-36 with modified four-wheel landing gear, later modified as a RB-36E.

B-36A

Production variant, unarmed, used for training, 22 built, all but one converted to RB-36E.

XC-99

A cargo/transport version of the B-36. Only one sole example was ever produced.

B-36B

Armed production variant with six 3,500 hp (2,600 kW) R-4360-41 engines, 73 built, later conversions to RB-36D and B-36D.

RB-36B

Designation for 39 B-36Bs temporary fitted with a camera installation.

YB-36C

Projected variant of the B-36B with six 4,300 hp (3,200 kW) R-4360-51 engines driving tractor propellers, not built.

B-36C

Production version of the YB-36, completed as B-36Bs.

B-36D

Same as B-36B but fitted with four J47-GE-19 engines, two each in two underwing pods, 22 built and 64 conversions from B-36B.

RB-36D

Strategic reconnaissance variant with two bomb bays fitted with camera installation, 17 built and seven conversions from B-36B.

GRB-36D

Same as RB-36D but modified to carry a GRF-84F Thunderstreak on a ventral trapeze as part of the FICON program, 10 modified.

RB-36E

The YB-36A and 21 B-36As converted to RB-36D standards.

B-36F

Same as B-36D but fitted with six 3,800 hp (2,800 kW) R-4360-53 engines and four J47-GE-19 engines, 34 built.

RB-36F

Strategic reconnaissance variant of the B-36F with additional fuels capacity, 24 built.

B-36H

Same as B-36F with improved cockpit and equipment changes, 83 built.

NB-36H

One B-36H fitted with a nuclear reactor installation for trials, had a revised cockpit and raised nose. This was intended to evolve into the Convair X-6.

RB-36H

Strategic reconnaissance variant of the B-36H, 73 built.

B-36J

High altitude variant with strengthened landing gear, increased fuel capacity, armament reduced to tail guns only and reduced crew, 33 built.

YB-60

Originally designated the YB-36G, s/n 49-2676 and 49-2684. Project for a jet-powered swept wing variant. Due to the difference from a standard B-36 it was re-designated the YB-60.

Related models

In 1951, the USAF asked Convair to build a prototype of an all-jet variant of the B-36. Convair complied by replacing the wings on a B-36F with swept wings, from which were suspended eight Pratt & Whitney XJ57-P-3 jet engines. The result was the B-36G, later renamed the Convair YB-60. The YB-60 was deemed inferior to Boeing's YB-52, and the project was terminated.

Just as the C-97 was the transport variant of the B-50, the B-36 was the basis for the Convair XC-99, a double-decked military cargo plane that was the largest piston engined, land-based aircraft ever built, and the longest practical aircraft (185 ft/56 m) of its era. The sole example built was extensively employed for nearly a decade, especially for cross-country cargo flights during the Korean War. In 2005, this XC-99 was dismantled in anticipation of its being moved from the former Kelly Air Force Base, now the Kelly

Field Annex of Lackland AFB in San Antonio, Texas, where it had been retired since 1957. The XC-99 was subsequently relocated to the National Museum of the United States Air Force at Wright-Patterson Air Force Base near Dayton, Ohio for restoration, with C-5 Galaxy transports carrying pieces of the XC-99 to Wright-Patterson as space and schedule permitted.

A commercial airliner derived from the XC-99, the Convair Model 37, never left the drawing board. It would have been the first "jumbo" airliner.

Operators



Convair RB-36H-55-CF Peacemaker 52-1383 of the 72d Strategic Reconnaissance Wing landing at RAF Burtonwood, Lancashire, England in October 1956

 United States

- United States Air Force

5th Strategic Reconnaissance Wing, January 1951–September 1958, Fairfield-Suisun AFB (later renamed Travis AFB), California (also RB-36)

6th Bombardment Wing, August 1952–August 1957, Walker AFB, New Mexico

7th Bombardment Wing, June 1948–May 1958, Carswell AFB, Texas

9th Strategic Reconnaissance Wing, May 1949–April 1950, Fairfield-Suisun AFB (later renamed Travis AFB), California (also RB-36)

11th Bombardment Wing, December 1948–December 1957, Carswell AFB, Texas

28th Strategic Reconnaissance Wing, July 1949–May 1957, Ellsworth AFB, South Dakota (also RB-36)

42d Bombardment Wing, April 1953–September 1956, Loring AFB, Maine

72d Strategic Reconnaissance Wing, October 1952–January 1959, Ramey AFB, Puerto Rico (also RB-36)

92d Bombardment Wing, July 1951–March 1956, Fairchild AFB, Washington
95th Bombardment Wing, August 1953–February 1959, Biggs AFB, Texas
99th Strategic Reconnaissance Wing, August 1951–September 1956, Fairchild AFB, Washington (also RB-36)

Survivors



B-36J AF Serial Number 52-2220 on display in the Cold War Gallery at the National Museum of the United States Air Force

Only four (and a half) B-36 type aircraft survive today, from the 384 produced.

- YB-36/RB-36E AF Serial No. 42-13571. This was the first prototype to be converted to the bubble canopy used on production B-36s. It was on display in the 1950s and 1960s at the former site of the Air Force Museum, now the National Museum of the United States Air Force, at Wright-Patterson Air Force Base near Dayton, Ohio. When the museum's current location at Wright-Patterson was being developed in the late 1950s, the cost of moving the bomber was more than simply flying a different B-36 to the new location and the aircraft was slated to be scrapped. It was cut up at the old museum site by the summer of 1972. Instead, private collector Walter Soplata bought it and transported the pieces by truck to his farm in Newbury, Ohio, where it sits today in several large pieces. The bomb bay currently contains a complete P-47N still packed in its original shipping crate.
- RB-36H-30-CF AF Serial No. 51-13730, is on display at the Castle Air Museum at the former Castle Air Force Base in Atwater, California.
- B-36J-1-CF AF Serial No. 52-2217, is on display at the Strategic Air and Space Museum, formerly located at Offutt Air Force Base, and now just off base near Ashland, Nebraska.
- B-36J-1-CF AF Serial No. 52-2220, is on display at the National Museum of the United States Air Force, (formerly The U.S. Air Force Museum) at Wright-Patterson Air Force Base near Dayton, Ohio. Its flight to the museum from Davis-Monthan Air Force Base in Arizona on 30 April 1959 was the last flight of a B-36. This B-36J replaced the former Air Force Museum's original YB-36 AF Serial Number 42-13571. This was also the first aircraft to be placed in the Museum's new display hangar, and was not moved again until relocated to the Museum's

latest addition in 2003. It is displayed alongside the only surviving example of the massive 9 ft (2.7 m) XB-36 wheel and tire.

- B-36J-10-CF, AF Serial No. 52-2827, the final B-36 built, named "The City of Fort Worth", was loaned to the city of Fort Worth, Texas on 12 February 1959. It sat on the field at the Greater Southwest International Airport until that property was redeveloped as a business park (some attempts were made to begin restoration there, during in the 1970s). It then moved to the short-lived Southwest Aero Museum, which was located between the former Carswell Air Force Base (now NAS Carswell Joint Reserve Base) and the former General Dynamics (now Lockheed Martin) assembly plant, where it was originally built; some restoration took place while at the plant. As Lockheed Martin had no place to display the finished aircraft, and local community efforts in Fort Worth to build a facility to house and maintain the massive aircraft fell short, the USAF Museum retook possession of the aircraft and it was transported to Tucson, Arizona for loan to the Pima Air & Space Museum. It is now restored and reassembled at that museum, just south of Davis-Monthan AFB, Arizona and is displayed at that location.

Also related is the sole example of the Convair XC-99 cargo version which is undergoing restoration and reassembly at the National Museum of the United States Air Force at Wright-Patterson AFB in Dayton, Ohio.

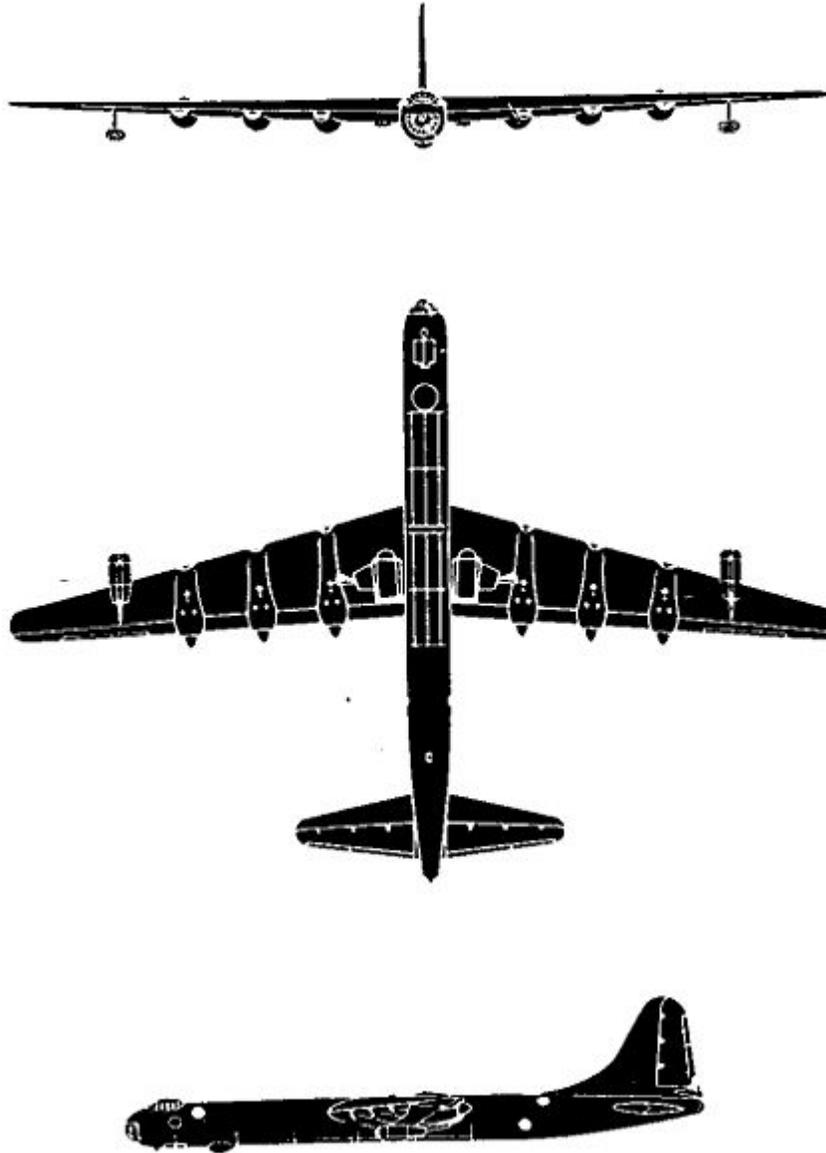
Notable incidents and accidents

Though the B-36 had a better than average overall safety record, 10 B-36s crashed between 1949 and 1954 (three B-36Bs, three B-36Ds, and four B-36Hs). Goleta Air and Space Museum maintains a web site with photographs and lengthy excerpts from the official crash reports. A total of 32 B-36s were written-off in accidents between 1949 and 1957 of 385 built. When a crash occurred, the magnesium-rich airframe burned readily.

B-36s were involved in two "Broken Arrow" incidents. On 13 February 1950, a B-36, serial number 44-92075, crashed in an unpopulated region of British Columbia, resulting in the first loss of an American atom bomb. The bomb's plutonium core was dummy lead, but it did have TNT, and it detonated over the ocean prior to the crew bailing out. Locating the crash site took some effort. Later in 1954, the airframe, stripped of sensitive material, was substantially destroyed (in situ) by a U.S. military recovery team.

On 22 May 1957, a B-36 accidentally dropped a Mark-17 hydrogen bomb on a deserted area while landing at Kirtland AFB in Albuquerque, New Mexico. Only the conventional trigger detonated, the bomb being unarmed. These incidents were classified for decades.

Specifications (B-36J-III)



General characteristics

- **Crew:** 13
- **Length:** 162 ft 1 in (49.42 m)
- **Wingspan:** 230 ft 0 in (70.12 m)
- **Height:** 46 ft 9 in (14.25 m)
- **Wing area:** 4,772 ft² (443.5 m²)
- **Airfoil:** NACA 63(420)-422 root, NACA 63(420)-517 tip
- **Empty weight:** 166,165 lb (75,530 kg)
- **Loaded weight:** 262,500 lb (119,318 kg) (combat weight)

- **Max takeoff weight:** 410,000 lb (186,000 kg)
- **Powerplant:**
 - 4× General Electric J47 turbojets, 5,200 lbf (23.2 kN) each
 - 6× Pratt & Whitney R-4360-53 "Wasp Major" radials, 3,800 hp (2,835 kW) each

Performance

- **Maximum speed:** 418 mph (363 knots, 672 km/h)
- **Cruise speed:** 230 mph (200 knots, 370 km/h)
- **Combat radius:** 3,985 mi (3,465 nmi, 6,415 km)
- **Ferry range:** 10,000 mi (8,700 nmi, 16,000 km)
- **Service ceiling:** 43,600 ft (13,300 m)
- **Rate of climb:** 1,995 ft/min (10.1m/s)

Armament

- **Guns:** 1 remotely operated tail turret with 2× 20 mm (0.787 in) M24A1 autocannons
- **Bombs:** 86,000 lb (39,000 kg) with weight restrictions, 72,000 lb (32,700 kg) normal

Notable appearances in media

In 1949, the B-36 was featured in the documentary film, *Target: Peace*, which was centered around the operations of the 7th Bombardment Wing at Carswell AFB. Other scenes included B-36 production at the Fort Worth plant.

In 1955, the film *Strategic Air Command* was released, starring James Stewart and June Allyson with Stewart playing a baseball star and his subsequent service in Strategic Air Command. The flying sequences (and sounds) of the B-36 dominate the film. This film remains as the only full-length film featuring this aircraft. As of 1 January 2011, this film is available for viewing on Netflix.

The documentary *Lost Nuke* (2004) chronicles a 2003 Canadian expedition that set out to solve the mystery of the world's first lost nuclear weapon. The team traveled to the remote mountain British Columbia crash site of 44-92075.

Lore

Throughout its time in service, the B-36 was the subject of USAF lore, some apocryphal, some containing a grain of truth.

"If all engines function normally at full power during the pre-takeoff warm-up, the lead flight engineer will sometimes say to the Aircraft Commander (AC), 'six turning and four

burning." Erratic reliability led to the wisecrack, 'two turning, two burning, two joking, and two smoking, with two engines not accounted for.'"
—Michael Daciek quoting Capt. Banda

Chapter 19

Ace Baby Ace and Adam RA-14 Loisirs

Ace Baby Ace

Ace Baby Ace



Role	Sports aircraft
National origin	USA
Manufacturer	Acro Sport
Designed by	Orland Corben

The **Ace Baby Ace** was the world's first aircraft to be marketed as a homebuilt aircraft when its plans were offered for sale in 1929. Plans are still available and Baby Aces are still being built today. Orland Corben designed a series of aircraft for the Ace Aircraft Manufacturing Company, the Baby Ace, Junior Ace, and Super Ace. Corbin's name was associated with the aircraft, and it is commonly known as the *Corben Baby Ace*.

Design

It is a single-seat parasol wing monoplane of conventional taildragger configuration. The fuselage is of fabric-covered tubular construction and the wings are wood. A variety of powerplants may be used, typically in the 65-100 hp (50-75 kW) range.

Operational History

In the mid 1950's Paul Poberezny, founder of the Experimental Aircraft Association bought the rights to the Ace aircraft, and produced a \$500 Baby Ace that was featured in Popular Mechanics. The series of articles were in conjunction with a CAA effort to revitalize American aviation by promoting amateur built aircraft.

Specifications (Typical Baby Ace D)

General characteristics

- **Crew:** one, pilot
- **Length:** 17 ft 11 in (5.46 m)
- **Wingspan:** 26 ft 6 in (8.08 m)
- **Height:** 6 ft 7 in ()
- **Wing area:** 110 ft² (10.22 m²)
- **Airfoil:** Clark Y
- **Empty weight:** 600 lb (270 kg)
- **Loaded weight:** 950 lb (430 kg)
- **Powerplant:** 1× Salmson, Szekely, Continental, or Anzani engine choices., 65-100 hp (50-75 kW)

Performance

- **Maximum speed:** 95 knots (110 mph, 176 km/h)
- **Service ceiling:** 10,500 ft (3,200 m)
- **Rate of climb:** 1,200 ft/min (370 m/min)

Adam RA-14 Loisirs

Adam RA-14 Loisirs



RA-14 Loisirs at Mery-sur-Oise airfield near Paris
in May 1957

Role	light sporting high-wing cabin monoplane
National origin	France
Manufacturer	Roger Adam
Designed by	Roger Adam
Status	Rights sold to Maranda Aircraft Company LTD in 1957
Primary user	private owners and aero clubs

The **RA-14 Loisirs** was a French two-seat high-wing light touring aircraft designed by Roger Adam shortly after World War II.

Design and production

The Loisirs ("Leisure") was designed in May 1945 by Etablissements Aeronautiques R. Adam. It was a tube, wood and fabric two-seater suitable for amateur construction. It was a high-wing braced monoplane of with fixed tail-wheel undercarriage. The seats were positioned side-by-side.

The company sold plans and manufactured parts for the aircraft which could be fitted with a range of engines of between 65 h.p and 80 h.p. These included the Regnier 4D and Continental A65, A75 and C90 engines.

The design rights were sold in 1957 to the Maranda Aircraft Company of Canada who sold plans for amateur construction of the Loisirs RA14BM1. More than 30 examples were built in North America.

Survivors

Of the French production of 40 Loisirs, 17 were active in 1965 and five were still flying in the country in 2001.

Specification

General characteristics

- **Crew:** 2
- **Length:** 6.99 m (22 ft 11 in)
- **Wingspan:** 10.90 m (35 ft 9 in)
- **Height:** 2.21 m (7 ft 3 in)

- **Wing area:** 16.0 m² (172 sq ft)
- **Empty weight:** 279 kg (616 lb)
- **Gross weight:** 479 kg (1,056 lb)
- **Powerplant:** 1 × Continental A65 air-cooled flat-four, 48 kW (65 hp)

Performance

- **Maximum speed:** 140 km/h; 76 kn (87 mph)
- **Cruise speed:** 121 km/h; 65 kn (75 mph)
- **Range:** 451 km; 243 nmi (280 mi)
- **Service ceiling:** 4,000 m (13,123 ft)